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Scientists' warning on the need for greater inclusion of dragonflies in global conservation

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Abstract

1. Dragonflies (Odonata) are ancient and familiar insects with a deep and strong cultural association with humans. They have an aquatic larval stage and an aerial adult stage, meaning that they respond to ecological conditions in both freshwater and the adjacent land surface.
2. Currently, 16% of dragonflies are threatened. Overall, they face several threats, especially habitat loss, landscape transformation, pollution, altered hydrology, spread of invasive alien species, as well as certain geographic-specific threats. Overarching these threats, which can be interactive with each other, is the issue of global climate change and attendant extreme weather events.
3. While many localised and habitat specialist species are under extreme threat, some other dragonfly species, mostly habitat generalists, benefit from certain moderate human activities, especially the creation of high-quality artificial ponds.
4. As well-researched insects, dragonflies play an important role in the protection of freshwater and riparian ecosystems. Dragonfly assemblages have great value as sentinels of both deteriorating environmental conditions and ecosystem recovery following restoration.
5. While similar findings on both threats and conservation actions are emerging across the world, certain ecosystems require targeted approaches. Above all, dragonflies must be included more widely in general biodiversity conservation activities and

For affiliations refer to page 15

policies. Overall, dragonflies are important targets, tools and model organisms for conservation action, and they can act as potential surrogates for other taxa that also depend on high water and riparian zone quality.

6. While research has paved the way to address these challenges, including the use of new technologies, we now urge that dragonflies be included more strongly in policy and management associated with both freshwater and adjacent terrestrial realms. This inclusion is especially effective as dragonflies have great appeal to a diverse community of people from odonatologists (citizen and professional) through to policymakers and managers, all of whom can employ dragonflies to contribute more to freshwater-associated conservation.
7. Finally, we propose an action plan focusing on five action points that address opportunities, and we suggest where dragonflies can play a greater role in freshwater/riparian zone conservation more widely across the world.

KEYWORDS

assessment, conservation policy and management, freshwater, monitoring, Odonata, riparian zone

INTRODUCTION

With over 6400 described species, dragonflies and damselflies (Odonata; hereafter collectively referred to as 'dragonflies', Figure 1) have a long and ancient lineage of a successful and overall unchanged body plan, with an aquatic larval stage and an aerial adult stage characterised by excellent flight abilities for efficient prey capture and even long-distance migration in some species.

Dragonflies are a key component of freshwater and neighbouring terrestrial ecosystems to which they export matter and energy as adults move away from the water (Popova et al., 2017; Rivas-Torres & Cordero-Rivera, 2024). As important predators, both as larvae and adults, across freshwater and terrestrial realms, they supply ecosystem services such as disease mitigation through the suppression of mosquitos (Córdoba-Aguilar et al., 2021) and of certain agricultural pests (May, 2019). They are also prey to small vertebrates such as fish and amphibians and, when they migrate, they can be an important part of the diet of migratory birds (May, 2013). Importantly, they have been especially valuable for assessing water and land quality regarding the state of naturalness (Samways, 2024). In view of their prominence at freshwaters and in surrounding landscapes, they are also important in environmental conservation education (Clausnitzer et al., 2017).

New dragonfly species are continually being discovered. In terms of threat, of those assessed on the IUCN Red List of Threatened Species (www.redlist.org), 29.4% are currently Data Deficient, while 55.4% are of Least Concern. A further 3.8% are Near Threatened and 4.8% are Vulnerable. The species of greater concern are those that are Endangered (5.0%), particularly those that are Critically Endangered (1.5%). Despite these numbers, dragonflies have lower levels of threat than the few other invertebrates comprehensively assessed. To

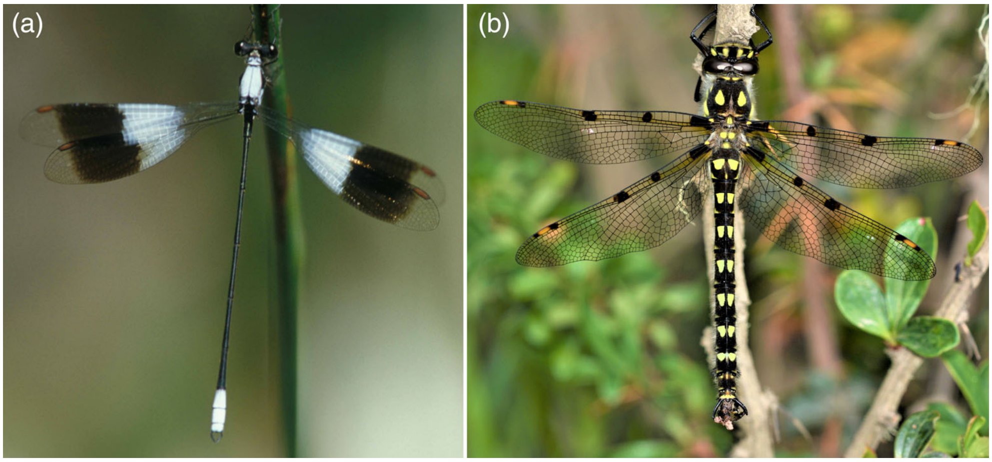

FIGURE 1 Dragonflies (order: Odonata) are composed mainly of two sub-orders, the damselflies (Zygoptera) and the 'true' dragonflies (Anisoptera). Shown here are two narrow-range endemics: *Chlorolestes umbratus* (Zygoptera) from the Cape Floristic Region, South Africa (a), and *Neopetalia punctata* (Anisoptera) from Bosques Patagónicos, Argentina (b). (Photos Michael Samways).

date, only one species, the St. Helena Darter (*Sympetrum dilatatum*), is red listed as Extinct (Pryce, 2021). However, 19 dragonfly species are assessed as Critically Endangered and possibly extinct in the wild. With 16% of all dragonfly species threatened, they are faring better than, for example, decapod crustaceans or fish (Sayer et al., 2025).

This paper is divided into three sections. In the first section, we address environmental risks associated with current changes in dragonfly populations and assemblages in certain ecosystems and relate these changes to particular dragonfly traits. We then draw attention to the significance of these changes in signalling human wellbeing and freshwater ecosystems conservation. Importantly, declines of both freshwaters and dragonflies are often based on poor/outdated policy decisions (Duffus et al., 2023). The second section highlights the progress made on conserving dragonflies and their habitats, both as a taxon per se and as a component of freshwater-associated ecosystems. Their conservation largely comes about from using effective whole-ecosystem approaches, our third major section. Conservation progress has been made largely through better landscape/waterscape management, restoration of terrestrial and freshwater ecosystems (Harabiš et al., 2023) and creation of high-quality artificial waterbodies (e.g., Smith et al., 2023; Vilenica et al., 2020), especially in regions where natural surface waterbodies are scarce or unpredictable (e.g., Suhling et al., 2006).

In sum, effective dragonfly conservation mostly hinges on whole-ecosystem approaches that consider both the aquatic and associated terrestrial realms. By using integrated cross-realm planning, freshwater benefits can be increased by up to 600% for a 1% reduction in terrestrial benefits. Furthermore, where freshwater biodiversity data are unavailable but aquatic connectivity is accounted for, freshwater benefits can still be doubled for negligible losses of terrestrial coverage (Leal et al., 2020).

We propose a five-point action plan for dragonflies and their host water/land ecosystems, based on research and successful projects in various parts of the world. The principles of these various successes now need to be expanded to cover more areas globally, while management needs to be instigated according to local socio-ecological contexts.

RISKS TO DRAGONFLIES

Threats to dragonflies

Dragonflies may be threatened by natural or anthropogenic causes. Natural disturbances have a frequency and intensity over time, enabling a period in which species can recover from the effects caused by the disturbance (Rykiel, 1985). Human activities do not usually follow this pattern, as the pressure exerted on ecosystems often intensifies as the density of human populations increases.

The most important overall threat to dragonflies is habitat deterioration and loss due to human activities (Figure 2). However, impacts vary both geographically and over time. Major stressors include land-use intensification (particularly forest loss in warm climates, intensive livestock farming and plantation forestry), water abstraction and agricultural pollution from run-off of pesticides and nutrients worldwide, with details of how these stressors impact dragonfly behaviour, life histories and populations now emerging (Barmentlo et al., 2019, 2021; Sugita et al., 2018; Termaat et al., 2023). Other stressors worldwide include urbanisation, mining, river regulation and damming, wetland draining and conversion and climate change, all leading to shifts and contractions of dragonfly distribution ranges (summarised in Córdoba-Aguilar et al., 2023; De Knijf, Billqvist, van Grunsven, Prunier, et al., 2024; Samways, 2024).

Regarding population changes over time, in Germany for example, comparing distributional changes of dragonflies over 35 years showed that running water species are on the rise, signalling conservation success achieved by better environmental management (Bowler et al., 2021). Unfortunately, at the global scale, currently the opposite is true, especially due to ongoing pollution of rivers by agriculture and industry (Connell, 2018).

Other specific threats are manifested as local impacts. For example, increasingly frequent and extreme weather events that decrease dragonfly populations (Vilenica et al., 2024a), use of insecticides (e.g., fipronil) and their metabolites that severely affect dragonfly survival in rice fields (Jinguji et al., 2018; Kasai et al., 2016), alien invasive fish species feeding on dragonfly larvae (Englund, 1999), invasive green anole lizards feeding on dragonfly adults (Karube, 2010), invasive crayfish that modify freshwater habitats by burrowing and removing aquatic vegetation (Nishijima et al., 2017), intensive fish ponds acting as ecological traps (Šigutová et al., 2015), invasive alien plants that alter natural riparian vegetation characteristics and shade out dragonfly habitats (Samways & Taylor, 2004), inappropriate landscaping (Lozano et al., 2022) and overgrazing causing deterioration of emergent macrophytes (Foote & Rice Hornung, 2005).

Typically, there are multiple stressors at a given place and time which can exacerbate impacts. Such multiple stressors on dragonflies may be the effect of deforestation, a major mining spill and various other impacts from agriculture and urbanisation at riverine habitats, e.g., on the Iberian Peninsula (Ferreras-Romero et al., 2009). In the Tropical Andes, the set of factors threatening dragonfly populations includes aquaculture, habitat loss due to agricultural expansion, clearing forests for wood and grazing pastures, mining and disorderly residential and commercial development near the species' natural habitats (Bota-Sierra et al., 2016). Some dragonflies have experienced different stressor sets over time. In the Netherlands, for example, human overuse of ponds, along with sulphur and nitrogen deposition, was later replaced by severe droughts and nitrogen deposition as the main stressors (Termaat et al., 2023).

Identifying the interaction between local stressors and the effects of regional, continental and global stressors is becoming increasingly important. For example, climate change is projected to cause a contraction in mire ecosystems and rare peatlands in southern Australia, compounding the impacts of other anthropogenic stressors such as fire and longwall coal mining, further threatening rare dragonflies, for example, *Petalura* species (Baird & Burgin, 2016; Keith et al., 2023).

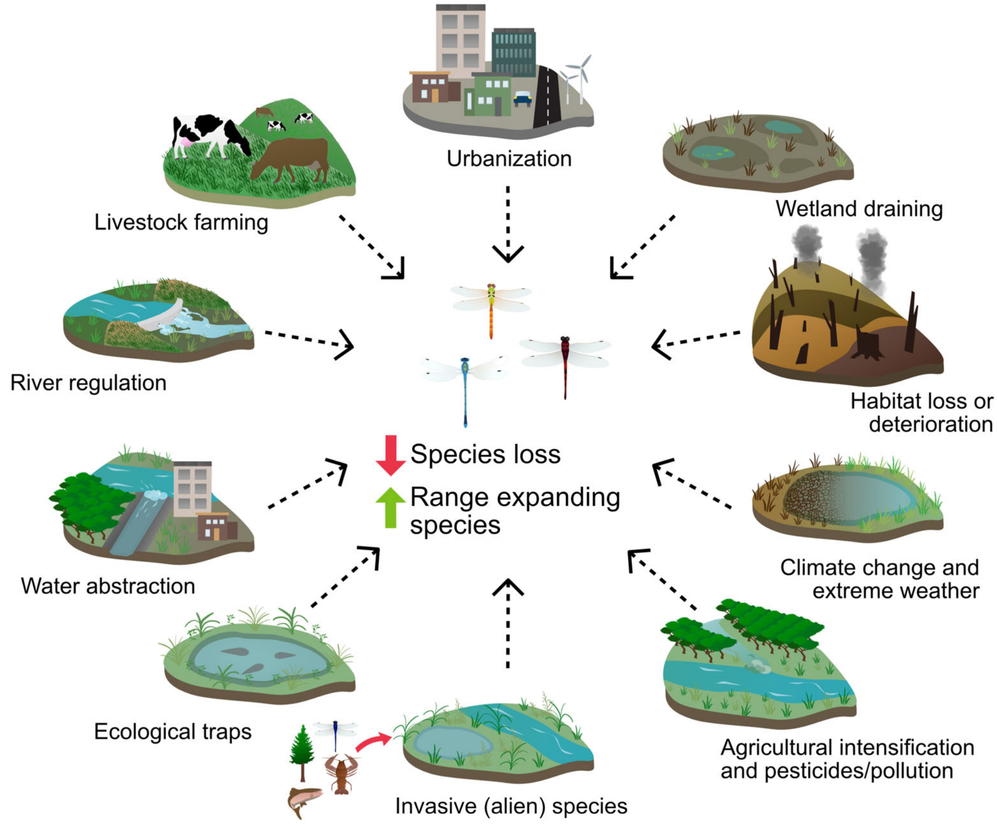

FIGURE 2 Global threats to dragonflies are multiple and often act together. Threats result in local and regional species losses, and in some regions create opportunities for some dragonfly species to expand their known geographic range. In some cases, range expansion enables them to outcompete indigenous ones.

Another especially harmful combination is between pollutants and environmental warming, as many pollutants, such as chlorpyrifos and neonicotinoid insecticides, are more toxic under warming conditions for freshwater invertebrates, including damselfly larvae (Dinh et al., 2016; Dinh et al., 2022).

In the Mediterranean, drought results in higher water demand for agriculture and tourism, leading to increased water abstraction from streams and rivers (De Knijf, Billqvist, van Grunsven, Prunier, et al., 2024; Tramblay et al., 2020). These impacts are often directly at the source and lead to dry rivers that are no longer suitable for dragonflies. For example, in central Europe, longer dry periods result in the partial drying out of important pond habitats, increasing the negative effects of nutrient enrichment, such as through atmospheric nitrogen deposition. This leads to changes in dragonfly diversity through predation and competition among themselves (Hogreve & Suhling, 2022). These interactive factors emphasise that the effects of climate change are complex and can be unpredictable and severe over large areas.

Effects associated with biological community change are nuanced, whether caused by local factors or in synergy with climate change. Species expanding their range as a result of climate change may appear at a new location, often leading to complex interspecific interactions; for instance, possible increased predation on the native species (Everling & Johansson, 2022). Such negative effects may be amplified by increasing temperatures causing range-expanding species to accelerate growth, which is not always the case with native species (e.g., Nagano et al., 2023).

Intrinsic vulnerability of dragonflies

A perceptual problem for policy making is biotic homogenisation, a process where spatially and temporally distant ecological communities become more similar to each other (Musters et al., 2019), with not necessarily a change in species richness (Rocha-Ortega et al., 2019). For dragonflies, this often means that habitat specialists are replaced by habitat generalists, leading to the misconception that dragonflies in general are doing well. These effects manifest as shifts in dragonfly assemblage structure, a response that appears to be global in extent (Datto-Liberato et al., 2024; Dolný et al., 2012; Vilenica, Brigić, Ergović, et al., 2024). Furthermore, assemblage shifts can be similar in urban and agricultural contexts, mostly with widespread habitat generalists replacing narrow-range habitat specialists, a common response in different areas (Kietzka et al., 2018; Smith et al., 2023).

The level of severity of threats is relative to dragonfly functional and ecological traits that have consequences for species' intrinsic vulnerability (Figure 3). Effective dragonfly conservation needs firstly to identify threats and extinction risk relative to the traits among populations and species (Rocha-Ortega et al., 2023). Dragonflies offer

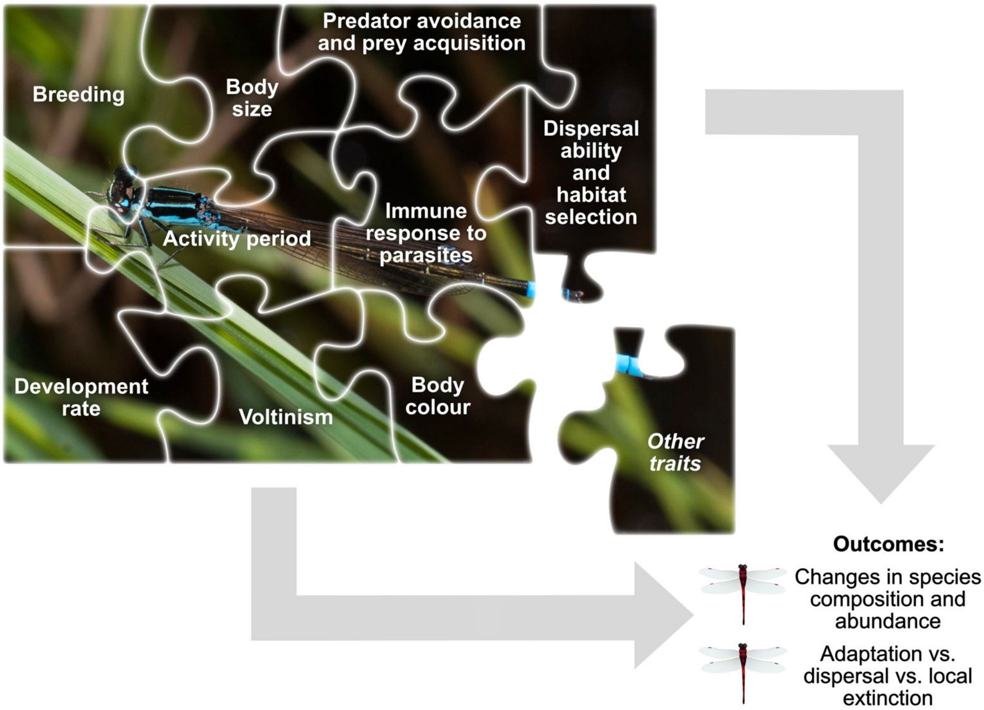

FIGURE 3 Dragonfly survival under different environmental scenarios depends on their traits. For some dragonflies, their traits can enable them to benefit from changing environmental conditions or signal adaptation to novel circumstances. Yet, some species may be unsuited for changing environmental conditions, leading to local extinction. While dragonfly trait databases are growing, other unknown traits may also contribute to adaptation in changing environments.

opportunities for investigating bioaccumulation and transfer of persistent pollutants thoughout aquatic and terrestrial food webs (Veseli et al., 2022) and risks of chemicals to dragonflies can effectively be assessed (Barmentlo et al., 2019; Sugita et al., 2018). Threats may be different for larvae versus adults, with instances of intra-generational carry-over effects. For example, Tüzün and Stoks (2017) have shown that exposure of the damselfly *Coenagrion puella* to the pesticide esfenvalerate during the aquatic larval stage greatly reduces the lifetime mating success of adult females.

However, the full extent of such ecotoxicological threats of chemicals to dragonflies remains largely unknown since dragonflies are not part of standardised risk assessment, and therefore data are sparse. This, in turn, hampers dragonfly populations because direct links between current surface water levels of pesticides and dragonfly decline can be overlooked (as exemplified for the neonicotinoid insecticide thiacloprid (Barmentlo et al., 2021)). There is also no scientific consensus nor are there standard test protocols on how to test for chemical threats to dragonflies. This limits our understanding of ecotoxicological risks since data between differentially executed studies are difficult to compare. Therefore, there is a need for the development of standard tests to accurately assess the diversity of lethal and sublethal effects to individual dragonfly species.

Behavioural changes are the fastest way that organisms respond to abrupt environmental alterations (Guillermo-Ferreira & Juen, 2021; Tynkkynen et al., 2008). For dragonflies, de Resen et al. (2021) found that territorial and reproductive behaviours were strongly linked to environmental conditions and that their diversity decreased due to changes in habitat integrity. In natural areas, species with different types of oviposition (inside plant material, on the outside of the substrate and on the water surface) are present, whereas in human-modified areas (such as agricultural areas, livestock areas and cities), only water surface oviposition prevailed. The same pattern was observed for territorial behaviours in males. Given the low quality of environments to defend in modified areas, the frequency of males exhibiting territorial behaviours was lower than in natural areas. Regarding foraging behaviour in both sexes, Suárez-Tovar et al. (2024) reported that dragonflies were less likely to fail in capturing prey in urbanised compared with natural areas.

In addition to behavioural adaptation, changes in dragonfly physiology occur in response to altered environmental conditions. In larvae, traits such as short development periods, tolerance to low oxygen concentrations and high levels of salinity and contaminants in allow individuals to remain in altered environments. In adults, high dispersal ability, efficient thermoregulation strategies and the ability to reproduce in sporadic and highly artificial habitats allow certain species to thrive in disturbed habitats (summarised in Chapter 4 of Samways (2024)). Furthermore, some artificial water bodies, such as urban stormwater ponds, may provide good breeding habitat for various dragonfly species (Perron et al., 2024; Suárez-Tovar et al., 2022). However, these assemblages usually consist of only resilient species with habitat generalist traits enabling them to increase their local density (Samways, 1989).

Some species have benefited enormously from moderate human activity as well as environmental change. For example, *Crocothemis erythraea* and *Trithemis annulata* in Europe, through high dispersal ability and habitat generalist traits, have capitalised on using constructed gravel pits and climate change to rapidly expand their geographic range (Termaat et al., 2019).

In contrast, certain species (often those with larger body size, laying eggs inside plants, longer pre-reproductive phases and colour dimorphism between sexes) are more sensitive to environmental degradation and prone to extinction (Rocha-Ortega et al., 2023). This pattern is evident in Amazonian forested streams, where human transformation of riparian vegetation and water quality selects for larger water surface egg-laying species (Pereira et al., 2019), and where some flight behaviours are lost.

Changes in geographic distributions are greatly influenced by individual species' traits, and conservation measures must also consider those traits. For example, across North America and Europe, standing water dragonfly species have wider and more northern distribution ranges compared with running water species (Hof et al., 2006). Holocene history has provided some interesting insights. Widespread dispersal after the Last Glacial Maximum was limited to a subset of aquatic invertebrate species (e.g., those species with active dispersal modes and larger body sizes) colonising newly available habitats in faraway places. Thus, species with limited dispersal ability will likely not be able to track their temperature niches given ongoing climate change and landscape fragmentation unless provided with stepping stone habitats (Cortés-Guzmán et al., 2024). In contrast, among African dragonflies, which mostly escaped the direct impact of ice sheets, the association between habitat preference and range size is weak, as these ecological traits are interactive with biological traits such as phenology and mobility (Deacon et al., 2021). This suggests that conservation efforts should focus on assemblages representing a range of dragonfly traits.

Furthermore, distribution ranges across elevation gradients can also determine dragonfly species vulnerability to extinction. Species that inhabit tropical high mountain ecosystems are more vulnerable to the challenges imposed by climate change, due to the specific requirements and high levels of endemism (Bota-Sierra et al., 2021).

The development of trait databases is helping to improve dragonfly conservation action (e.g., Ferreira et al., 2023; Waller et al., 2019). These databases serve as comprehensive repositories of information, contributing to our understanding of which threats are widespread and even global, as opposed to which ones are local, especially when a specific stressor or set of stressors is firmly identified (De Knijf, Billqvist, van Grunsven, Prunier, et al., 2024). Furthermore, such trait databases allow for investigation of the relationships between distribution patterns and multiple traits simultaneously, and for predicting the intrinsic vulnerability and sensitivity of species, enhancing the basis of decisions on dragonfly conservation in a changing world.

PROGRESS TOWARDS DRAGONFLY CONSERVATION

Conservation principles and strategies

Conservation is about preventing further loss of biodiversity while also improving and/or restoring degraded conditions. This enables natural ecosystem components and processes to remain ecologically resilient in the face of future environmental change. This process is known as future proofing (Lynch et al., 2024) and involves a series of steps: targeted research (+ contribution from citizen science) → threat assessment (by conservation organisations) → conservation action (coming about mostly through local policy and followed by local management) → re-assessment (mostly by land stewards, researchers and/or non-governmental organisations) → continued management to improve conditions (land stewards) → monitoring over time (land stewards, researchers and/or non-governmental organisations) → recommendations and information sharing for policy improvement (at all levels from individuals, human communities through to global assessments and strategy development), including communication of results in study locations (by local societies, government officials, non-governmental organisations) (Figure 4). Implemented through a decolonial lens, such capacity building can be tailored to local needs and knowledge, led by local communities (Trisos et al., 2021).

Monitoring the state of dragonfly populations, species and/or assemblages is essential. Decisions on monitoring and evaluation during the early stages of conservation programmes are critical to ensure that populations, habitats and ecosystems are effectively and efficiently assessed over time to measure the level of conservation success. Dragonflies play a major role as a tractable component of freshwater assessment and monitoring (Šigutová et al., 2023), with even novel insights such as their use to monitor radioactivity levels coming to light (Vukoja et al., 2024). However, there must be cognizance of natural environmental heterogeneity and ecosystem dynamics that drive dragonfly assemblage shifts over space and time (Kietzka et al., 2021).

Freshwater bodies in many parts of the world are already being monitored to determine their state relative to ongoing changes in pressures and threats (e.g., Pozojević et al., 2023; Vilenica & Mihaljević, 2022). European Union Member States must report on the status of freshwater habitats under the Habitats Directive and for the Water Framework Directive. However, smaller water bodies such as ponds and ditches, as well as intermittent freshwater habitats in the Mediterranean, are underrepresented in conservation policy, although promising signs are emerging through an increase in research effort in various countries (Hill et al., 2018; Korbaa et al., 2018; Vilenica & Mihaljević, 2022).

Building a robust baseline for conservation is critical for addressing knowledge gaps relating to dragonflies. Enhancing local expertise through collaborative initiatives that promote local capacity building is essential for developing effective taxonomic knowledge and then developing effective conservation strategies. Updating species lists, developing field guides and digital applications that include taxonomic

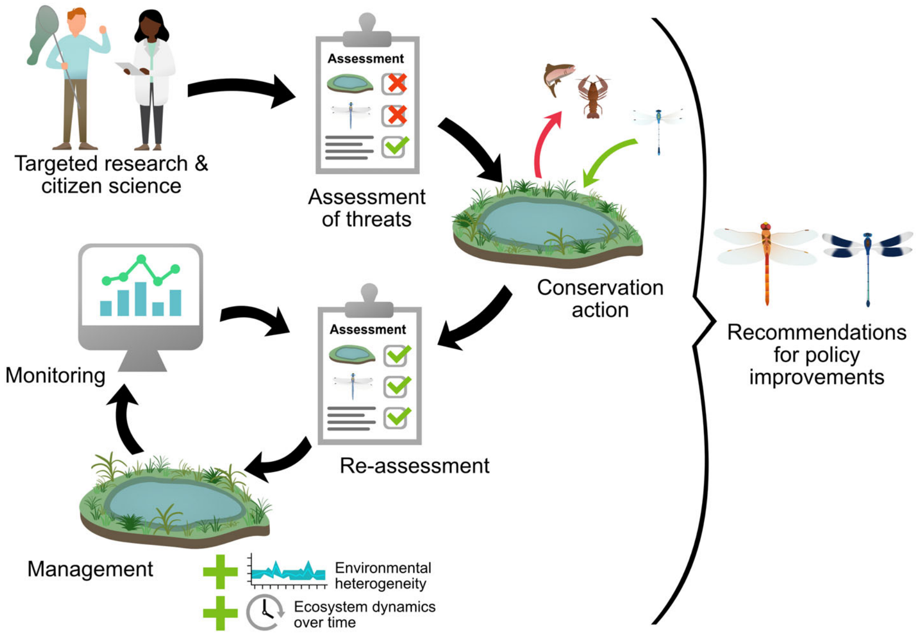

FIGURE 4 A key conservation strategy is the assessment of dragonfly habitats, informed by targeted research and supplemented by additional sources such as data collected through citizen science. This is followed by monitoring to measure conservation progress. Assessment and monitoring feed into recommendations for conservation policy improvement across aquatic and terrestrial space.

and ecological aspects, and emphasising the cultural role of species in each specific region, will promote knowledge of dragonflies within human communities. This, in turn, will facilitate engagement and curiosity about the group, fostering a desire to protect them, translating to feedback into policy making. A prime example of such efforts is the consolidation of the new annotated checklist for Colombia, where 536 species were identified through meticulous revision of literature and biological collections over the past two decades by 17 local researchers. This foundational information illuminated knowledge gaps and identified threatened species crucial to nationwide conservation efforts (Bota-Sierra et al., 2024).

Monitoring must also be feasible and practical over the long term. In Brazil, the use of coarse taxonomic ratios (dragonfly suborders and families) in forest streams is a robust and easily applicable tool for monitoring environmental conditions across forest and savanna biomes (e.g., Oliveira-Junior & Juen, 2019; Ribeiro et al., 2021). This has led to the Brazilian government training field technicians to monitor deforestation using the observed proportions of damselflies (Zygoptera) and 'true' dragonflies (Anisoptera) (Brasil et al., 2020). However, while this approach can also work in other tropical forest ecosystems, it has limitations in different ecosystem types (Šigutová et al., 2023). Nevertheless, progress is being made towards developing simple methods that non-specialists can apply so that dragonflies can be widely used to monitor ecological integrity and environmental quality on a global scale (Bried et al., 2020).

Assessment and monitoring of sites for dragonfly conservation can also benefit other organisms, a process known as surrogacy. However, this umbrella effect is never perfect and depends on the spatial scale of measurement and can vary according to life stage (larva versus adult) and geographic location. Of note is an area of South Africa with high levels of local endemism, where both larvae and adults perform well in representing 93% of the local mayfly, stonefly and caddisfly fauna. All these groups depend on the quality of both the water and the riparian zone (Kietzka et al., 2019). While other locations may not attain such high levels of surrogacy, dragonflies nevertheless are excellent indicators of high-quality habitats for various groups. Along with measurements of water and riparian vegetation types, dragonflies can indicate deteriorating or improving water quality and overall habitat conditions (summarised in Samways, 2024).

Conservation action and management for dragonflies

Rarely are all the ramifications of potential and actual threats, and interactions between the various types of threats, fully identified. However, some threats to freshwaters are clear; for example, habitat loss, water abstraction, impacts of invasive alien species, changing conditions stemming from climate change, and impacts of emerging contaminants (Reid et al., 2019). Research can assess the relative degree of these threats, investigate management options, implement management actions and then determine how effective the management actions have been (van Strien & Grunsven, 2023). Critically, there is a need to understand the extent to which conservation action provides resilience for populations and ecosystems into the future that enables them not only to survive impacts but also to recover from them. Although tools to monitor habitat restoration have been developed for dragonflies, long-term experience is still required (e.g., Vorster et al., 2020). The importance of long-term monitoring

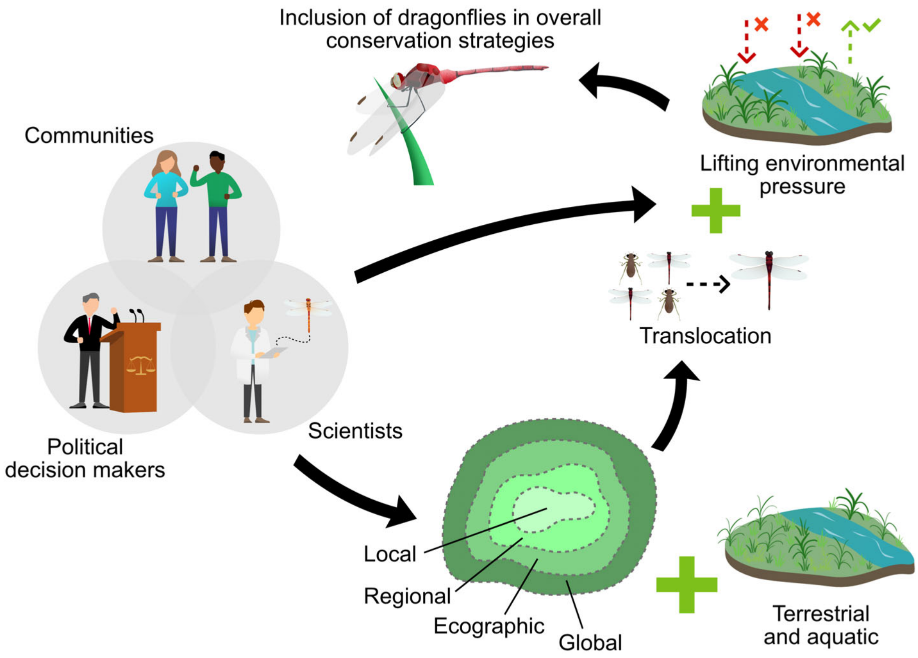

FIGURE 5 Scientists, communities and political decision makers drive conservation action. Conservation action needs to consider multiple spatial scales, and both terrestrial and aquatic spaces. Some successful dragonfly conservation strategies include lifting current environmental pressures, avoiding future pressures and translocating dragonflies from healthy populations to restore dragonfly assemblages.

was seen for *Leucorrhinia dubia*, where continuous monitoring and site management that consider the impact of interventions on the entire biological community are essential to sustain a reintroduced population over the long term (Šigutová et al., 2025).

These fundamentals need to be viewed against competing conservation interests. Dragonflies are sometimes neglected despite being effective for freshwater assessment, as has happened in Sweden, for example (Al Jawaheri & Sahlén, 2017). In turn, the targets set for habitats under the European Habitats Directive focus on vegetation but not on other taxonomic groups such as dragonflies (De Knijf, Billqvist, van Grunsven, Prunier, et al., 2024). Clearly, there is much room for further discussion among freshwater conservationists towards more complementary conservation strategies that involve dragonflies (Figure 5).

Certain dragonfly species can recover well when threats are lifted. For instance, the gomphid *Stylurus flavipes* recolonised West and Central Europe when the water quality of rivers improved due to European and national legislation such as the Water Framework Directive and the Habitats Directive (Kalkman et al., 2018). In South Africa, rare dragonflies recolonised areas formerly invaded by alien trees following the large-scale removal of these trees (Deacon & Samways, 2017).

While a few at-risk dragonfly species have benefitted from translocation efforts (Harabiš et al., 2023), ideally conservation efforts should benefit several species, which is often the case when habitats/ecosystems are restored. Importantly in the case of dragonflies, conservation action must include both the freshwater and adjacent riparian zone. Although for many dragonfly species this also includes the wider terrestrial area beyond the water body and riparian zone, where individuals can optimise maturing into adults, and can readily fly across the landscape to find optimal habitat, hunting sites and mates (Taylor, 2006).

In turn, effective dragonfly conservation is important at various spatial scales: locally, across landscapes or waterscapes, within political boundaries (states, nations, etc.) and at regional, ecogeographic and global scales. The point is that the limits of species distribution ranges do not follow political borders, despite these units often being ones used in conservation action. This reality necessitates cooperation between different sets of political decision-makers, underlining the need for regional and international collaboration in conservation efforts. Currently, there are large research networks and databases that allow studies and actions involving continental scales, as in Latin America (Alves-Martins et al., 2024), Africa (Clausnitzer et al., 2012) and Europe (Boudot & Kalkman, 2015). Another example is the Pampa biome of Latin America, which requires conservation integration of Argentina, Brazil and Uruguay (Pires et al., 2024). In the Amazon, although having many protected areas, dragonfly conservation depends heavily on different types of conservation units and integrated conservation policies between the states across a wide area (Brasil et al., 2020).

Conservation of dragonflies at the population level

Focusing on a particular species means taking care of its populations and maintaining overall population genetic diversity and resilience in the face of multiple stressors and threats which may vary from one place to another (Orr et al., 2024). Some, often isolated, populations may require special attention because the genetic composition may differ from other sub-populations. For instance, North Africa is a hotspot of cryptic diversity of Palearctic species. Molecular studies of North African dragonflies have demonstrated clear genetic differentiation between North African and European populations in both dragonflies (e.g., Simonsen et al., 2020) and damselflies (e.g., Ferreira et al., 2016), despite low morphological variation. Where the focus is on one population and its intrinsic vulnerability, information may also be extrapolated to other, sympatric species.

Across the world, the first goal at the species level is to protect the local habitat (Figure 5). However, where degradation has gone too far, it may be necessary to undertake restoration towards natural high-quality habitat conditions, perhaps also involving re-introduction into historical habitats or assisted dispersal to unoccupied suitable habitats of the most viable life stages (e.g. *Urothemis edwardsii* in Algeria (Khelifa et al., 2016); *Leucorrhinia dubia* in Czechia (Dolný et al., 2018)).

EFFECTIVE WHOLE-ECOSYSTEM STRATEGIES

Conservation of dragonfly habitats and their host ecosystems

As with all organisms, each dragonfly individual interacts with many other individuals of the same or different species. As apex, relatively non-specialised predators, dragonflies, especially the larvae, can exert high pressure on prey populations that become too abundant, including disease vector mosquito species (e.g., Córdoba-Aguilar et al., 2021). A prime goal in conservation is to maintain natural conditions and support ecosystem functioning, especially in protected areas (PAs), which often support source populations. Most PAs also benefit local human communities, especially through ecotourism initiatives, thus having multiple benefits.

Because PAs are fixed spatial entities, their effectiveness can shift relative to climate change. Thus, long-term resilience of PAs relies on their integration within wider landscapes. Large-scale conservation corridor networks (interconnected strips of natural land in an otherwise transformed landscape) that are well maintained and connected to PAs can support high levels of natural freshwater habitat heterogeneity (especially in terms of plant communities), making them attractive to many dragonfly species. Importantly, these conservation corridors extend the operational area of adjacent PAs and connect PAs at the regional scale, enabling dragonflies to persist across their entire distribution ranges (e.g., van Schalkwyk et al., 2023). Both standing and running water bodies in conservation corridors can support equal levels of functional richness and species variation compared with those in neighbouring PAs. Thus, maintaining a mosaic of small water bodies of various types and that encompass a wide range of environmental conditions best enhances dragonfly conservation in transformed landscapes, as was found for the subtropical region of South Africa (Deacon et al., 2024) (Figure 6).

In another South African biodiversity hotspot, biosphere reserves (which involve various levels of human activity) support large numbers of species, many of which are endemic. While the partially utilised buffer and transition zones surrounding the fully protected core zones may experience some habitat degradation, they can support a range of species when habitat heterogeneity is maintained, thereby increasing the dragonfly species diversity of entire reserve areas (Grant & Samways, 2011).

For running water, it is vital to maintain headwater streams and associated aquifers which are not only of high value for localised endemics but also for supplying good quality water to lower reaches. However, in regions such as North Africa, the conservation of running water wetlands is often overlooked compared with standing water wetlands, despite their role in harbouring sensitive and endemic species assemblages (Khelifa et al., 2021). For standing water, a variety of ponds in a landscape (collectively making up a diverse 'pondscape') is the best approach for supporting full dragonfly assemblages (Jooste et al., 2020). However, socio-ecological considerations, such as how local communities use water and wetland resources, must be included.

Often, where there is only minor transformation or degradation of the local ecosystem, it can be a relatively simple task to recover habitat conditions to encourange ecologically resilient natural ecosystems, especially those hosting source habitats from which individuals can disperse. These source habitats also include the land areas surrounding the freshwater body. This is a concept with wide applicability (Bried et al., 2023; Strieb et al., 2022), and translates to protection and management of whole dispersal networks, including functionally connected breeding areas and steppingstone habitats in the intervening matrix. Due to limited resources, generally there is a need to prioritise areas for protection and management, with dragonflies contributing greatly to this process.

Restoration of ecosystems and dragonfly assemblages

While it is imperative to maintain the high quality of natural habitats even in the transformed matrix, sometimes they are so degraded (for example, in terms of altered vegetation structure and density, leading to local changes in hydrology) that it is necessary to intervene with effective management and restoration (e.g., Harabiš et al., 2023; Wildermuth & Schiess, 1983). This is a whole-system approach, with dragonflies being an important component of overall biodiversity. Beyond removal of stressors, the priority for restoration is to enable recovery of water, soil and plants (Figure 7). Mostly, this is a passive approach where the ecosystem is left to recover on its own, the success of which depends on the extent to which biodiversity is regionally present to re-colonise the focal area. This was the case for many rare and endemic dragonflies after widescale removal of very harmful invasive alien trees in South Africa (Samways & Sharratt, 2010).

Hydrological restoration of drained or peat-extracted mires (e.g., in Canada, Europe, Southeast Asia) is being increasingly used

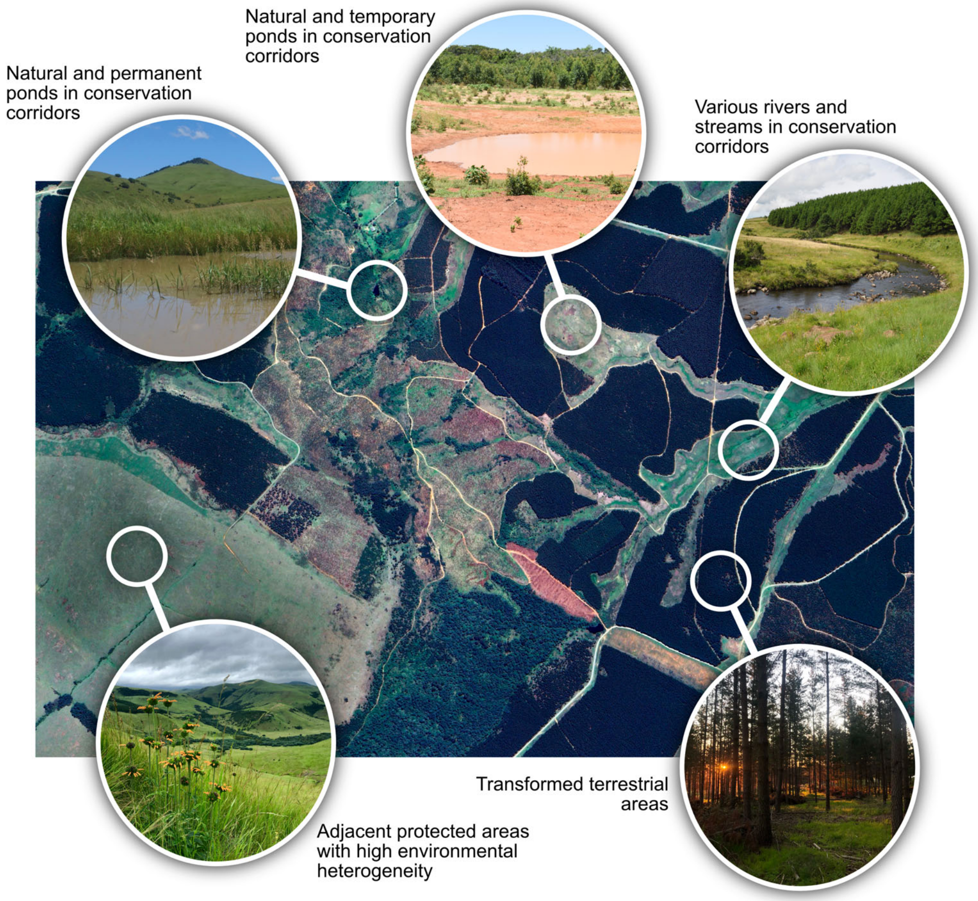

FIGURE 6 Protected areas play an important role in protecting dragonfly assemblages in transformed landscapes. The effectiveness of protected areas is greatly enhanced by using adjacent conservation corridors in the transformed matrix to extend the operational surface of protected areas. These conservation corridors must be carefully managed and must contain a rich variety of rivers, streams, permanent ponds and temporary ponds, while also supporting high-quality terrestrial areas.

for climate change mitigation and biodiversity conservation (e.g., Joosten et al., 2017), providing habitat for mire specialist and generalist dragonflies (e.g., Canadian peatland species; Hilton, 1987). In central Queensland, Australia, previous policy changes to reduce the number of artesian bores across the Great Artesian Basin have resulted in some recovery of spring discharges in endangered spring wetlands, which provide habitat for a suite of microendemic threatened species, including snails, plants and the tiny dragonfly *Nannophya fenshami* (DCCEEW, 2023). However, in some long-utilised landscapes, as in Europe, some species that are recognised as locally indigenous may be at risk from restoration activities such as reforestation, particularly when using fast-growing exotic tree species (Cordero-Rivera et al., 1999).

The positive value of certain novel habitats

Not all water and land transformations are harmful to certain sub-sets of dragonflies, and in some cases, some rare species can also benefit (Kašák et al., 2023). Small reservoirs that do not greatly change water flow can increase local standing water dragonfly diversity while having little impact on the running water species above and below the reservoir (Steytler & Samways, 1995).

High-quality artificial ponds in both rural and urban environments (Figure 8) can increase the local density of many species, although these species are mostly widespread habitat generalists. Restoration of degraded ponds, or new ponds, and especially those ponds ecologically designed and managed appropriately, can greatly boost local dragonfly numbers, with results similar in different geographical locations (Goertzen & Suhling, 2015; Lozano et al., 2022; Vilenica et al., 2020). Abandoned mining ponds can also provide opportunities for certain species once toxic materials are cleared and water quality and the historic plant community have been re-established (Harabiš et al., 2013). Abandoned rice paddies that are sensitively managed can also be turned into dragonfly refuges (Giuliano & Bogliani, 2019). Stormwater ponds similarly encourage sub-sets of local dragonflies to establish when these ponds have well-developed wetland plant assemblages (Perron & Pick, 2020) and low levels of fish predation (Šigutová et al., 2022).

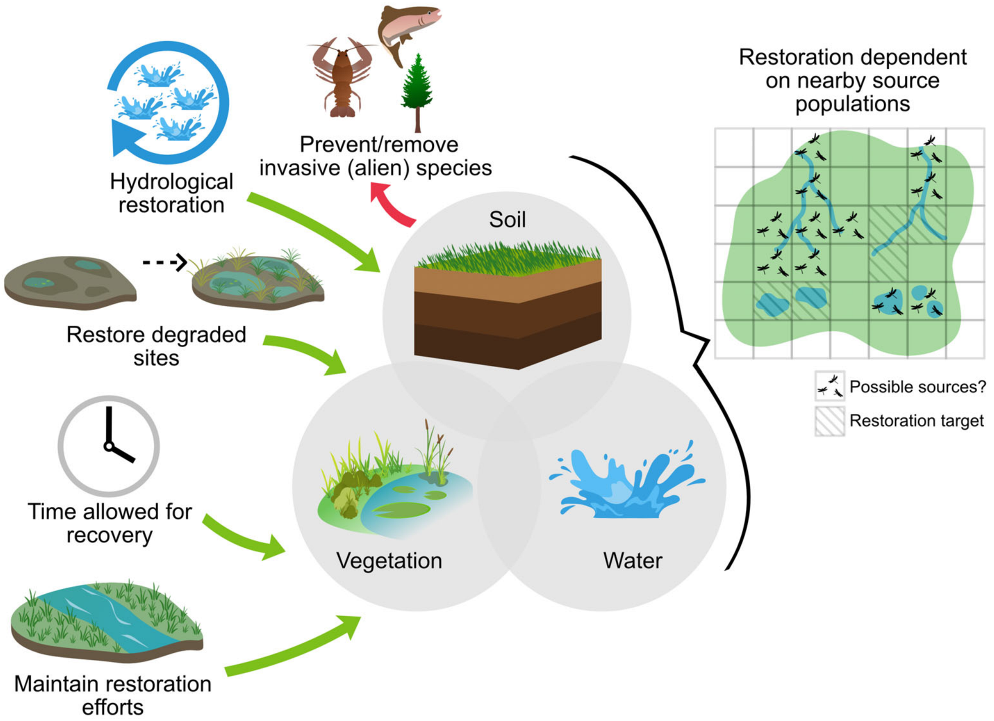

FIGURE 7 Dragonfly assemblage restoration efforts need to consider the removal of invasive species, landscape-scale hydrological restoration, the restoration of degraded habitats and the maintenance of overall restoration efforts. Other key considerations are that restoration requires enough time, and restoration success depends on natural capital from surrounding good-quality habitats being available.

Artificial ponds in dry areas can enable some species to survive droughts (e.g., de Paz et al., 2020). At the southern tip of Africa, a region prone to El Niño-Southern Oscillation events, extreme weather events such as droughts and floods can cause pond water levels to fluctuate greatly. Dragonflies decline in abundance and shift from occupying stressed natural habitats to occupying managed artificial ponds to survive prolonged drought periods. While the highest value is for widespread species, even some endemic and/or running water species can temporarily benefit from the presence of suitable artificial pond refuges (Deacon et al., 2019).

Improving dragonfly conservation through social engagement

Assessment and research on appropriate conservation management actions are often enhanced by citizen science involvement. This begins with citizen scientists being able to identify dragonfly species in the field. Because dragonflies are relatively easy to identify to species level, and it is the species level rather than higher-level taxon levels that confers assessment of ecosystems, the group lends itself to conservation action. Thus, field guides and identification applications are an essential first step towards dragonfly and freshwater conservation, and involving local, regional and global dragonfly societies is highly advantageous (e.g., Worldwide Dragonfly Association) (Ožana et al., 2019). Civil society engagement, along with sound research findings, offer the potential to effect conservation policy at various spatial scales from local to global. A dialogue with stakeholders can help to build consensus and resolve policy formation conflicts (Köthe et al., 2023).

Another important factor is the instigation of policies that focus on overall biodiversity protection, with dragonflies being a major component. This progress also depends on developing effective educational programmes (Clausnitzer et al., 2017) that involve and are driven by the younger generation of conservationists (Dillon et al., 2023).

Policy development for dragonfly assessment and monitoring

We need to know whether dragonfly populations are steady (or at least showing 'natural' population fluctuations), declining in local abundance and/or showing range contraction or expansion (and in the case of the latter, may pose competition for other species (Cranston et al., 2023)). This topic is already incorporated in some political actions, like the European Habitats Directive, which involves monitoring of priority species to obtain long-term estimations of their population trends. Population assessment leads to the determination of the extent and level of threat(s) relative to the traits of the focal species and for whole assemblages.

While this is done at the local scale, a combination of assessments across a region and among regions helps greatly in determining both local scale trends in population stability alongside those at greater

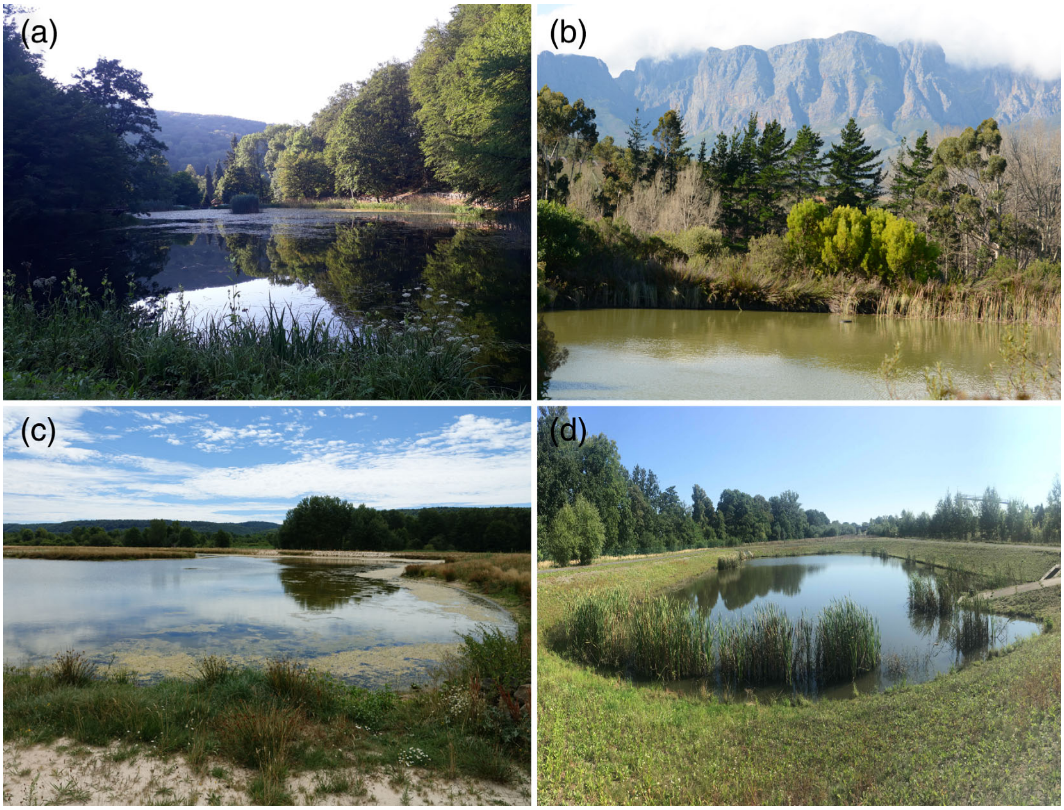

FIGURE 8 Artificial ponds play an important role in maintaining local dragonfly assemblages and where standing water bodies are scarce, as in Papuk Nature Park, Croatia (a), and the Cape Floristic Region, South Africa (b). Ponds designed for urban mitigation, as in south-western Germany (c) and stormwater ponds, as in Czechia (d) are also effective. (Photos in sequence: Marina Vilenica, Michael Samways, Jürgen Ott, Aleš Dolný).

spatial scales. This combination of data also throws light on global assessments in the sense that the more localised the geographic range of a species, the more locally threats and the protocols for the recovery can be identified. In contrast, a more widespread species may not only have a greater range of habitat sensitivities but also may face a different set of threats in different geographic areas. Following management action for environmental improvement, populations then require monitoring to establish which management options are the most appropriate (van Strien & Grunsven, 2023).

Large-scale monitoring and assessment require a modern approach powered by people (a combination of odonatologists, entomologists and naturalists), technologies (such as miniaturised tracking devices, repurposed weather radar, water condition assessment and sediment and water eDNA) and citizen science (social programmes, events and societies, applications, web platforms and databases). Importantly, for accurate monitoring, technologies must be integrated in a way that allows valid comparisons among populations, assemblages and ecosystems that vary over time.

Standardised data on dragonflies remain scarce and are generally limited to a few countries (Bried et al., 2020). Opportunistic data, on the other hand, are more widely available and cover many countries and regions (Termaat et al., 2019). Great strides are being made across Europe in this regard. For example, the emerging DRAGON project (https://www.fondationbiodiversite.fr/en/the-frb-in-action/programs-and-projects/le-cesab/dragon/; accessed 16 July 2024) aims to strengthen our understanding of the drivers of dragonfly diversity change at the European level and to provide tangible recommendations for mitigating human impacts by combining opportunistic and standardised datasets. Therefore, it aims to set up a common European database for opportunistic and monitoring data, providing analytical tools in synergy with the emergence of Dragonfly Conservation Europe (DCE) to collate, map and harmonise existing opportunistic and monitoring datasets available in Europe. The goal of the project is to provide tools and outputs to improve dragonfly conservation. DCE aims to bring the strength of the European odonatological network together, facilitate further collaboration and be a first contact point for developments at the European level. Furthermore, the ‘Assess-to-Plan’ methodology of the IUCN Species Survival Commission is now enabling much progress in the process of moving from assessment to planning for threatened European dragonflies (De Knijf, Billqvist, van Grunsven, Assandri, et al., 2024). It recommends actions aimed at improving European policy and planning mechanisms and describes urgent requirements for protecting, restoring and managing key habitats and populations to avert further declines and drive on-ground recovery.

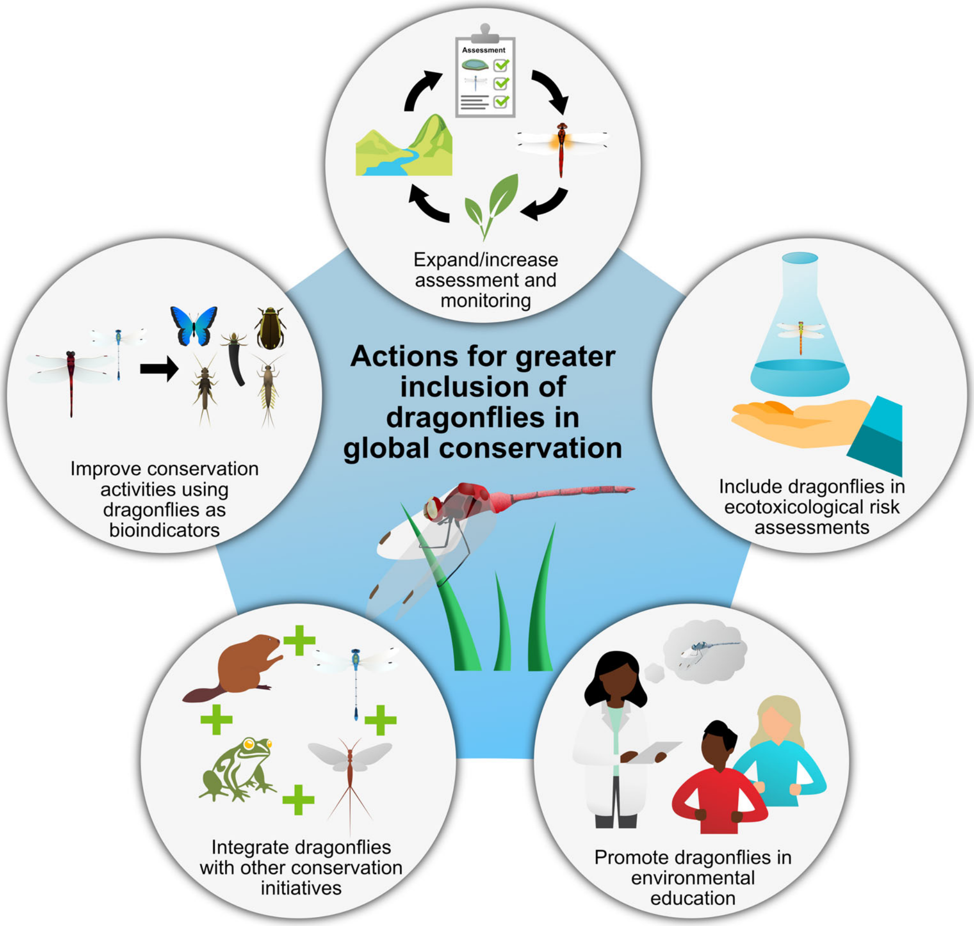

FIGURE 9 Global dragonfly conservation hinges on five fundamental actions, implemented across various spatial scales and by various stakeholders.

AN ACTION PLAN FOR PROMOTION OF DRAGONFLIES IN FRESHWATER AND RIPARIAN CONSERVATION

Firstly, recovery solutions require understanding the threats, and continued characterisation and prediction of dragonfly responses to the major pressures are essential. New collaborative efforts like the GLiTRS project (https://glitrs.ceh.ac.uk/), a global expert elicitation process for insects, the Status of Insects initiative (https://statusofinsects.github.io/index.html), and the DRAGON project will help in this regard. We now need to translate the dragonfly responses, along with their trait values, into species-level indicators which together make up their assemblage response to ensure dragonflies are part of broader freshwater conservation. Some practical assessment tools have already gained traction, such as the development of a practical manual for the Dragonfly Biotic Index (Samways & Simaika, 2016), which is now being applied in Africa, South America (Brazil and Argentina) (Datto-Liberato et al., 2024) and Europe, with locally appropriate modifications (Bilková et al., 2025; Šigutová et al., 2024).

In North America, studies are underway to estimate land cover and climate change sensitivities for large swaths of dragonfly diversity, both to help prioritise species for protection and to use them in freshwater biomonitoring. We further need flexible thinking around conservation risks and a readiness to refine species' threat status (whether at jurisdictional, regional or global levels) with new data and changing environmental conditions. This approach requires quantitative alertness to any major changes in trends for better or worse. For example, distribution records are often the best available information for dragonflies and can be leveraged towards extinction risk assessments and status updates (Bried & Rocha-Ortega, 2023; Rocha-Ortega et al., 2020).

We also need strong baseline information for knowing and dealing with threat responses and risk status. A large unknown exists in the risk assessment of chemicals to dragonflies due to a lack of data and the absence of standard test protocols. For dragonfly recovery, citizen science continues to play a major role in establishing baselines (e.g., Kalkman et al., 2018). Yet major challenges persist, such as standardising these efforts to infer population trends and expanding geographic coverage in developing regions (Sanchez Herrera et al., 2024).

Integration of citizen science with major technological approaches may be ideal for insect monitoring (e.g., Sheard et al., 2024), and the use of smartphone recording apps is underway for dragonflies (e.g., Ožana et al., 2019). Radar-based remote sensing holds promise to detect and enumerate large dragonfly concentrations (e.g., mass emergence events and migrations) and even to discern species identities (Bauer et al., 2024). Other technologies, such as eDNA, may help to detect species of conservation concern (Schmidt et al., 2021).

We summarise the information above by proposing a positive future for the involvement of dragonflies in freshwater and riparian zone conservation in terms of five conservation actions which apply globally but are honed to be applicable/effective to local conditions (Figure 9):

1. **Expand and increase assessment and monitoring**. Dragonflies are accessible, established sentinels of a changing world, and it is important to continue and expand the assessment and monitoring of their population levels, distributions and assemblage structures. This information feeds into conservation listing frameworks (e.g. IUCN) and large initiatives for understanding conservation risks and declines from human pressures, such as the Status of Insects initiative, and the DRAGON and GLiTRS projects. At the same time, dragonflies are especially important for assessing and monitoring the status of both freshwaters and riparian zones. Internationally recognised approaches and protocols are already available, while recognising that citizen science and emerging technologies are also enhancing progress in assessment and monitoring. Ultimately, baseline trend or status information from assessment and monitoring must be translated into adaptive management practices and policy decisions.
2. **Include dragonflies in standard ecotoxicological risk assessment**. Use dragonflies to assess specific impacts of pollutants as a component of the Organisation for Economic Co-operation and Development protocols. Current standardised risk assessment does not include dragonflies for the ecotoxicological testing of chemicals. However, several authors have successfully developed and executed such tests with dragonflies, showcasing that risks of chemicals can effectively be assessed. The next step would be a debate and consensus by scientists on i) a standard test life stage and species (of which the larvae, and eurytopic and widespread genera *Ischnura* and *Coenagrion* show promise) ii) culture and testing conditions, as well as iii) a debate and consensus by policymakers on the active need for the inclusion of dragonflies in standardised risk assessment.
3. **Improve landscape conservation activities using dragonflies**. These include conservation actions that link water and land, improve connectivity among habitat patches and buffer water/land quality. As such, landscape-scale conservation requires thinking not only locally within specific habitat patches but also about (meta)communities of interacting organisms across patches. Often the design and management principles (e.g. removing or mitigating dispersal barriers) are the same from one geographic area to another, but actions must be honed to suit local conditions, including the socio-ecological context. With the landscape approach, it is generally assumed that actions benefitting dragonflies will also benefit co-occurring organisms that have similar requirements or traits.
4. **Ensure integration of dragonflies with other conservation initiatives**. Dragonflies have huge potential to measure the success of, for example, the reduction of human exploitation of wetlands through sustainable land-use practices, beaver reintroduction programmes, habitat restoration programmes (including managing impactful alien species), sustainable drainage systems development in cities enhancing hydrometeorological resilience while creating novel dragonfly habitat and clean energy projects. By including dragonflies, conservation policies and management globally will become more effective. Comparing findings from across the world helps form the comparative baseline, and actions are tailored to suit local conditions through community-based solutions.
5. **Promote dragonflies in environmental education**. Because dragonflies are such familiar, conspicuous organisms with sentinel value for both water and adjacent lands, their conservation should be promoted more widely by using a variety of media platforms to bring public attention to the conservation of freshwater systems. Novel ways to encourage involvement by diverse societies, covering various age and racial groups, across a spectrum of levels of education, and in agreement with modern societal trends are needed to ensure that the true value of dragonflies as sentinels for conservation is realised going forward.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

No new data were used for the research described in this article.

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REFERENCES

Al Jawaheri, R. & Sahlén, G. (2017) Negative impact of lake liming programmes on the species richness of dragonflies (Odonata): a study from southern Sweden. *Hydrobiologia*, 788, 99–113. Available from: https://doi.org/10.1007/s10750-016-2990-5

Alves-Martins, F., Stropp, J., Juen, L., Ladle, R.J., Lobo, J.M., Martinez-Arribas, J. et al. (2024) Sampling completeness changes perceptions of continental scale climate–species richness relationships in odonates. *Journal of Biogeography*, 51, 1148–11162. Available from: https://doi.org/10.1111/jbi.14810

Baird, I.R.C. & Burgin, S. (2016) Conservation of a groundwater-dependent mire-dwelling dragonfly: implications of multiple threatening processes. *Journal of Insect Conservation*, 20, 165–178. Available from: https://doi.org/10.1007/s10841-016-9852-3

Barmentlo, S.H., Schrama, M., De Snoo, G.R., Van Bodegom, P.M., van Nieuwenhuijzen, A. & Vijver, M.G. (2021) Experimental evidence for neonicotinoid driven decline in aquatic emerging insects. *PNAS*, 118, e2105692118. Available from: https://doi.org/10.1073/pnas.2105692118

Barmentlo, S.H., Vriend, L.M., van Grunsven, R.H. & Vijver, M.G. (2019) Environmental levels of neonicotinoids reduce prey consumption, mobility and emergence of the damselfly Ischnura elegans. *Journal of Applied Ecology*, 56, 2034–2044. Available from: https://doi.org/10.1111/1365-2664.13459

Bauer, S., Tielens, E.K. & Haest, B. (2024) Monitoring aerial insect biodiversity: a radar perspective. *Philosophical Transactions of the Royal Society B*, 379, 20230113.

Bilková, E., Šigutová, H., Pyszko, P., Prieložná, V. & Dolný, A. (2025) Adapting a country-specific dragonfly biotic index: framework for seven central European countries and transboundary patterns analysis. *Ecological Indicators*, 170, 113111. Available from: https://doi.org/10.1016/j.ecolind.2025.113111

Bota-Sierra, C.A., Álvarez-Álvarez, K., Amaya, V., Carrillo Camargo, B., Garzón-Salamanca, L.L., Hoyos, A. et al. (2024) Commented checklist of the Odonata from Colombia. *International Journal of Odonatology*, 27, 103–150. Available from: https://doi.org/10.48156/1388.2024.1917280

Bota-Sierra, C.A., Flórez-V, C., Escobar, F., Sandoval-H, J., Novelo-Gutiérrez, R., Londoño, G.A. et al. (2021) The importance of tropical mountain forests for the conservation of dragonfly biodiversity: a case from the Colombian Western Andes. *International Journal of Odonatology*, 24, 233–247. Available from: https://doi.org/10.23797/2159-6719_24_18

Bota-Sierra, C.A., Maufray, B., Palacino-Rodríguez, F., Hofmann, J., Tennessen, K., Rache, L. et al. (2016) Estado de conservación de las libélulas de los Andes Tropicales. In: Tognelli, M.F., Lasso, C.A., Bota-Sierra, C.A., Jiménez-Segura, L.F. & Cox, N.A. (Eds.) *Estado de Conservación y Distribución de la Biodiversidad de Agua Dulce en los Andes Tropicales*. Gland, Suiza, Cambridge and Arlington: UICN, pp. 67–86.

Boudot, J.-P. & Kalkman, V.J. (2015) *Atlas of the European dragonflies and damselflies*. The Netherlands: KNNV publishing.

Bowler, D.L., Eichenberg, D., Conze, K.-J., Suhling, F., Baumann, K., Benken, T. et al. (2021) Winners and losers over 35 years of dragonfly and damselfly distributional change in Germany. *Diversity and Distributions*, 27(8), 1353–1366. Available from: https://doi.org/10.1111/ddi.13274

Brasil, L., Dantas, D., Polaz, C., Raseira, M., Juen, L. & Bergamini, L. (2020) Monitoramento participativo em igarapés de unidades de conservação da Amazônia brasileira utilizando Odonata. *Boletin de la Sociedad de Odonatologia Latinoamericana*, 2, 8–13.

Bried, J., Ries, L., Smith, B., Patten, M., Abbott, J., Ball-Damerow, J. et al. (2020) Towards global volunteer monitoring of odonate abundance. *Bioscience*, 70, 914–923. Available from: https://doi.org/10.1093/biosci/biaa092

Bried, J.T., Alves-Martins, F., Brasil, L.S. & McCauley, S.J. (2023) Metacommunity concepts, approaches, and directions with Odonata. In: Córdoba-Aguilar, A., Beatty, C.D. & Bried, J.T. (Eds.) *Dragonflies and damselflies: model organisms for ecological and evolutionary research*, 2nd edition. New York: Oxford University Press, pp. 233–246. Available from: https://doi.org/10.1093/oso/9780192898623.003.0017

Bried, J.T. & Rocha-Ortega, M. (2023) Using range size to augment regional priority listing of charismatic insects. *Biological Conservation*, 283, e110098. Available from: https://doi.org/10.1016/j.biocon.2023.110098

Clausnitzer, V., Dijkstra, K.-D.B., Koch, R., Boudot, J.P., Darwall, W., Kipping, J. et al. (2012) Focus on African freshwaters: hotspots of dragonfly diversity and conservation concern. *Frontiers in Ecology and the Environment*, 10(3), 129–134. Available from: https://doi.org/10.1890/110247

Clausnitzer, V., Simaika, J.P., Samways, M.J. & Daniel, B.A. (2017) Dragonflies as flagships for sustainable use of water resources in environmental education. *Applied Environmental Education and Communication*, 16, 196–209. Available from: https://doi.org/10.1080/1533015X.2017.1333050

Connell, D.W. (2018) *Pollution in tropical aquatic systems*. Boca Raton, Florida, USA: CRC Press, Taylor & Francis Group. 9781351075879.

Cordero-Rivera, A., Utzeri, C. & Santolamazza-Carbone, S. (1999) Emergence and adult behaviour of *Macromia splendens* (Pictet) in Galicia, northwestern Spain (Anisoptera: Corduliidae). *Odonatologica*, 28, 333–342.

Córdoba-Aguilar, A., Beatty, C.D. & Bried, J.T. (2023) *Dragonflies and damselflies*, 2nd edition. New York, USA: Oxford University Press.

Córdoba-Aguilar, A., San Miguel-Rodríguez, M., Rocha-Ortega, M., Lanz-Mendoza, H., Cime-Castillo, J. & Benelli, G. (2021) Adult damselflies as possible regulators of mosquito populations in urban areas. *Pest Management Science*, 77, 4274–4287. Available from: https://doi.org/10.1002/ps.6496

Cortés-Guzmán, D., Sinclair, J., Hof, C., Kalusche, J.B. & Haase, P. (2024) Dispersal, glacial refugia and temperature shape biogeographical patterns in European freshwater biodiversity. *Global Ecology and Biogeography*, 33, e13885. Available from: https://doi.org/10.1111/geb.13886

Cranston, J., Isaac, N.J.B. & Early, R. (2023) Associations between a range-shifting damselfly (Erythromma viridulum) and the UK's resident Odonata suggest habitat sharing is more important than antagonism. *Insect Conservation and Diversity*, 16, 416–426. Available from: https://doi.org/10.1111/icad.12630

Datto-Liberato, F.H., Lopez, V.M., Quinaia, T., do Valle Junior, R.F., Samways, M.J., Juen, L. et al. (2024) Total environment sentinels: dragonflies as ambivalent/amphibiotic bioindicators of damage to soil and freshwater. *The Science of the Total Environment*, 934, 173110. Available from: https://doi.org/10.1016/j.scitotenv.2024.173110

DCCEEW. (2023) *Approved conservation advice for the community of native species dependent on natural discharge of groundwater from the great Artesian Basin*. Canberra, Australia: Department of Climate Change, Energy, the Environment and Water.

De Knijf, G., Billqvist, M., van Grunsven, R., Assandri, A., Bedjanič, M., Conze, K.-J. et al. (2024) Moving from Assessment to Planning for Threatened European Dragonflies. In: *A report to the European Commission by the IUCN SSC Dragonfly Specialist Group and the IUCN SSC Conservation Planning Specialist Group*. Gland, Switzerland: IUCN.

De Knijf, G., Billqvist, M., van Grunsven, R.H.A., Prunier, F., Vinko, D., Trottet, A. et al. (2024) European Red List of Dragonflies and Damselflies (Odonata). In: *Measuring the Pulse of European Biodiversity*. Brussels, Belgium: European Commission.

de Paz, V., Baños-Picón, L., Rosas-Ramos, N., Tobajas, E., Tormos, J. & Asís, J.D. (2020) The role of artificial ponds in maintaining dragonfly populations in an intensified farmland landscape. A case of study in Zamora, Spain. *Journal of Natural History*, 54, 2439–2454. Available from: https://doi.org/10.1080/00222933.2020.1850901

de Resen, B.O., Ferreira, V.R.S., Brasil, L.S., Calvão, L.B., Mendes, T.P., de Carvalho, F.G. et al. (2021) Impact of environmental changes on the behavioral diversity of the Odonata (Insecta) in the Amazon. *Scientific Reports*, 11(1), e9742. Available from: https://doi.org/10.1038/s41598-021-88999-7

Deacon, C. & Samways, M.J. (2017) Conservation planning for the extraordinary and endangered Spesbona damselfly. *Journal of Insect Conservation*, 21, 121–128. Available from: https://doi.org/10.1007/s10841-017-9960-8

Deacon, C., Samways, M.J. & Pryke, J.S. (2019) Aquatic insects decline in abundance and occupy low-quality artificial habitats to survive hydrological droughts. *Freshwater Biology*, 64, 1643–1654. Available from: https://doi.org/10.1111/fwb.13360

Deacon, C., Samways, M.J. & Pryke, J.S. (2021) Relative importance of ecological versus biological traits in driving range sizes of African dragonflies. *Journal of Biogeography*, 48, 1309–1321. Available from: https://doi.org/10.1111/jbi.14077

Deacon, C., Samways, M.J. & Pryke, J.S. (2024) Conservation corridors with many small waterbodies support dragonfly functional diversity across a transformed landscape mosaic. *Diversity and Distributions*, 30, e13939. Available from: https://doi.org/10.1111/ddi.13939

Dillon, A., Simaika, J., Clausnitzer, V., Thompson, A., White, E., Montes-Fontalvo, J. et al. (2023) Bridging people and nature through Odonata. In: Córdoba-Aguilar, A., Beatty, C.D. & Bried, J.T. (Eds.) *Dragonflies and damselflies: model organisms for ecological and evolutionary research*, 2nd edition. New York, USA: Oxford University Press, pp. 413–426.

Dinh, K.V., Janssens, L. & Stoks, R. (2016) Exposure to a heat wave under food limitation makes an agricultural insecticide lethal: a mechanistic laboratory experiment. *Global Change Biology*, 22, 3361–3372. Available from: https://doi.org/10.1111/gcb.13415

Dinh, K.V., Konestaba, H.S., Borgå, K., Hylland, K., Macaulay, S.J., Jackson, M.C. et al. (2022) Interactive effects of warming and pollutants on marine and freshwater invertebrates. *Current Pollution Reports*, 8(4), 341–359. Available from: https://doi.org/10.1007/s40726-022-00245-4

Dolný, A., Harabiš, F., Bárta, D., Lhota, S. & Drozd, P. (2012) Aquatic insects indicate terrestrial habitat degradation: changes in taxonomical structure and functional diversity of dragonflies in tropical rainforest of East Kalimantan. *Tropical Zoology*, 25, 141–157. Available from: https://doi.org/10.1080/03946975.2012.717480

Dolný, A., Šigutová, H., Ožana, S. & Choleva, L. (2018) How difficult is it to reintroduce a dragonfly? Fifteen years monitoring Leucorrhinia dubia at the receiving site. *Biological Conservation*, 218, 110–117. Available from: https://doi.org/10.1016/j.biocon.2017.12.011

Duffus, N.E., Echeverri, A., Dempewolf, L., Noriega, J.A., Furumo, P.R. & Morimoto, J. (2023) The present and future of insect biodiversity conservation in the neotropics: policy gaps and recommendations. *Neotropical Entomology*, 52, 407–421. Available from: https://doi.org/10.1007/s13744-023-01031-7

Englund, R.A. (1999) The impact of introduced poeciliid fish and Odonata on the endemic *Megalagrion* (Odonata) damselflies of Oahu Island, Hawaii. *Journal of Insect Conservation*, 3, 225–243.

Everling, S. & Johansson, F. (2022) The effect of temperature and behaviour on the interaction between two dragonfly larvae species within the native and expanded range. *Ecological Entomology*, 47, 460–474. Available from: https://doi.org/10.1111/een.13130

Ferreira, S., Boudot, J.-P., El Haissoufi, M., Alves, P.C., Thompson, D.J., Brito, J.C. et al. (2016) Genetic distinctiveness of the damselfly *Coenagrion puella* in North Africa: an overlooked and endangered taxon. *Conservation Genetics*, 17, 985–991.

Ferreira, V.R.S., de Resende, B.O., Bastos, R.C., da Brito, J.S., de Carvalho, F.G., Calvão, L.B. et al. (2023) Amazonian Odonata Trait Bank. *Ecology and Evolution*, 13, e10149. Available from: https://doi.org/10.1002/ece3.10149

Ferreras-Romero, M., Márquez-Rodríguez, J. & Ruiz-García, A. (2009) Implications of anthropogenic disturbance factors on the Odonata assemblage in a Mediterranean fluvial system. *International Journal of Odonatology*, 12, 413–428.

Foote, A.L. & Rice Hornung, C.L. (2005) Odonates as biological indicators of grazing effects on Canadian prairie wetlands. *Ecological Entomology*, 30, 273–283.

Giuliano, D. & Bogliani, G. (2019) Odonata in rice agroecosystems: testing good practices for their conservation. *Agriculture, Ecosystems & Environment*, 275, 65–72. Available from: https://doi.org/10.1016/j.agee.2019.01.009

Goertzen, D. & Suhling, F. (2015) Central European cities maintain substantial dragonfly species richness—a chance for biodiversity conservation? *Insect Conservation and Diversity*, 8, 238–246. Available from: https://doi.org/10.1111/icad.12102

Grant, P.B. & Samways, M.J. (2011) Micro-hotspot determination and buffer zone value for Odonata in a globally significant biosphere reserve. *Biological Conservation*, 144, 772–781. Available from: https://doi.org/10.1016/j.biocon2010.2010.11008

Guillermo-Ferreira, R. & Juen, L. (2021) Odonate ethodiversity as a bioindicator of anthropogenic impact. *International Journal of Odonatology*, 24, 149–157. Available from: https://doi.org/10.23797/2159-6719_24_11

Harabiš, F., Simaika, J.P., Dolný, A., Luke, S.A., Elo, M., Bried, J.T. et al. (2023) Odonata as focal taxa for ecological restoration. In: Córdoba-Aguilar, A., Beatty, C.D. & Bried, J.T. (Eds.) *Dragonflies and damselflies: model organisms for ecological and evolutionary research*, 2nd edition. New York: Oxford University Press, pp. 401–412.

Harabiš, F., Tichanek, F. & Tropek, R. (2013) Dragonflies of freshwater pools in lignite spoil heaps: restoration management, habitat structure and conservation value. *Ecological Engineering*, 55, 51–61. Available from: https://doi.org/10.1016/j.ecoleng.2013.02.007

Hill, M.J., Hassall, C., Oertli, B., Fahrig, L., Robson, B.J., Biggs, J. et al. (2018) New policy directions for global pond conservation. *Conservation Letters*, 11(5), e12447. Available from: https://doi.org/10.1111/conl.12447

Hilton, D.J.F. (1987) Odonata of peatlands and marshes in Canada. *Memoirs of the Entomological Society of Canada*, 140, 57–63.

Hof, C., Brändle, M. & Brandl, R. (2006) Lentic odonates have larger and more northern ranges than lotic species. *Journal of Biogeography*, 33, 63–70. Available from: https://doi.org/10.1111/j.1365-2699.2005.01358.x

Hogreve, J. & Suhling, F. (2022) Development of two common dragonfly species with diverging occupancy trends. *Journal of Insect Conservation*, 26, 571–581. Available from: https://doi.org/10.1007/s10841-022-00396-1

Jinguji, H., Ohtsu, K., Ueda, T. & Goka, K. (2018) Effects of short-term, sublethal fipronil and its metabolite on dragonfly feeding activity. *PLoS One*, 13, e0200299. Available from: https://doi.org/10.1371/journal.pone.0200299

Jooste, M.L., Samways, M.J. & Deacon, C. (2020) Fluctuating pond water levels and aquatic insect persistence in a drought-prone Mediterranean-type climate. *Hydrobiologia*, 847, 1315–1326. Available from: https://doi.org/10.1007/s10750-020-04186-1

Joosten, H., Tanneberger, F. & Moen, A. (2017) *Mires and peatlands of Europe: status, distribution and conservation*. Stuttgart, Germany: Schweizerbart Science Publishers.

Kalkman, V.J., Boudot, J.-P., Bernard, R., De Knijf, G., Suhling, F. & Termaat, T. (2018) Diversity and conservation of European dragonflies and damselflies (Odonata). *Hydrobiologia*, 811, 269–282. Available from: https://doi.org/10.1007/s10750-017-3495-6

Karube, H. (2010) Endemic insects in the Ogasawara Islands: negative impacts of alien species and a potential mitigation strategy. In: Kawakami, K. & Okochi, I. (Eds.) *Restoring the Oceanic Island ecosystem, impact and Management of Invasive Alien Species in the Bonin Islands*. Switzerland: Springer, pp. 133–137 978-4-431-53858-5.

Kasai, A., Hayashi, T., Ohnishi, H., Suzuki, K., Hayasaka, D. & Goka, K. (2016) Fipronil application on rice paddy fields reduces densities of common skimmer and scarlet skimmer. *Scientific Reports*, 6, e23055. Available from: https://doi.org/10.1038/srep23055

Kašák, J., Holuša, O. & Mazalová, M. (2023) Artificial habitat – a chance for survival of a rare montane dragonfly (Odonata): case study on an alpine emerald (Somatochlora alpestris). *Journal of Insect Conservation*, 27, 315–321. Available from: https://doi.org/10.1007/s10841-023-00457-z

Keith, D.A., Benson, D., Baird, I.R.C., Watts, L., Simpson, C.C., Krogh, M. et al. (2023) Effects of interactions between anthropogenic stressors and recurring perturbations on ecosystem resilience and collapse. *Conservation Biology: The Journal of the Society for Conservation Biology*, 37(1), e13995. Available from: https://doi.org/10.1111/cobi.13995

Khelifa, R., Deacon, C., Mahdjoub, H., Suhling, F., Simaika, J.P. & Samways, M.J. (2021) Dragonfly conservation in the increasingly stressed African Mediterranean-type ecosystems. *Frontiers in Environmental Science*, 9, e660163. Available from: https://doi.org/10.3389/fenvs.2021.660163

Khelifa, R., Mellal, M.K., Zouaimia, A., Amari, H., Zebsa, R., Bensouilah, S. et al. (2016) On the restoration of the last relict population of a dragonfly Urothemis edwardsii Selys (Libellulidae: Odonata) in the Mediterranean. *Journal of Insect Conservation*, 20, 797–805. Available from: https://doi.org/10.1007/s10841-016-9911-9

Kietzka, G.J., Pryke, J.S., Gaigher, R. & Samways, M.J. (2019) Applying the umbrella index across aquatic taxon sets for freshwater assessment. *Ecological Indicators*, 107, e105655. Available from: https://doi.org/10.1016/j.ecolind.2019.105655

Kietzka, G.J., Pryke, J.S., Gaigher, R. & Samways, M.J. (2021) 32 years of essential management to retain value of an urban dragonfly awareness pond. *Urban Ecosystem*, 24, 1295–1304. Available from: https://doi.org/10.1007/s11252-021-01115-5

Kietzka, G.J., Pryke, J.S. & Samways, M.J. (2018) Comparative effects of urban and agricultural land transformation on Odonata assemblages in a biodiversity hotspot. *Basic and Applied Ecology*, 33, 89–98. Available from: https://doi.org/10.1016/j.baae.2018.08.008

Korbaa, M., Ferreras-Romero, M., Ruiz-García, A. & Boumaiza, M. (2018) TSOI—a new index based on Odonata populations to assess the conservation relevance of watercourses in Tunisia. *Odonatologica*, 47, 43–72. Available from: https://doi.org/10.3390/10.5281/zenodo.1239945

Köthe, S., Schneider, F.D., Bakanov, N., Brühl, C.A., Eichler, L., Fickel, T. et al. (2023) Improving insect conservation management through insect monitoring and stakeholder involvement. *Biodiversity and Conservation*, 32, 691–713. Available from: https://doi.org/10.1007/s10531-022-02519-1

Leal, C.G., Lennox, G.D., Ferraz, S.F.B., Ferreira, J., Gardner, T.A., Thomson, J.R. et al. (2020) Integrated terrestrial-freshwater planning doubles conservation of tropical aquatic species. *Science*, 370, 117–121. Available from: https://doi.org/10.1126/science.aba7580

Lozano, F., del Palacio, A., Ramos, L.S., Granato, L., Drozd, A. & Muzon, J. (2022) Recovery of local dragonfly diversity following restoration of an artificial lake in an urban area near Buenos Aires. *Basic and Applied Ecology*, 58, 88–97. Available from: https://doi.org/10.1016/j.baae.2021.11.006

Lynch, A.J., Hyman, A.A., Cooke, S.J., Capon, S.J., Franklin, P.A., Jähnig, S.C. et al. (2024) Future-proofing the emergency recovery plan for freshwater biodiversity. *Environmental Reviews*, 32, 350–365. Available from: https://doi.org/10.1139/er-2022-0116

May, M.L. (2013) A critical overview of progress in studies of migration of dragonflies (Odonata: Anisoptera), with emphasis on North America. *Journal of Insect Conservation*, 17, 1–15. Available from: https://doi.org/10.1007/s10841-012-9540-x

May, M.L. (2019) Odonata: who they are and what they have done for us lately: classification and ecosystem services of dragonflies. *Insects*, 10, e62. Available from: https://doi.org/10.3390/insects10030062

Musters, C.J.M., Hunting, E.R., Schrama, M., Cieraad, E., Barmentlo, S.H., Ieromina, O. et al. (2019) Spatial and temporal homogenisation of freshwater macrofaunal communities in ditches. *Freshwater Biology*, 64, 2260–2268. Available from: https://doi.org/10.1111/fwb.13415

Nagano, K., Hiraiwa, M.K., Ishiwaka, N., Seko, Y., Hashimoto, K., Uchida, T. et al. (2023) Global warming intensifies the interference competition by a poleward-expanding invader on a native dragonfly species. *Royal Society Open Science*, 10(11), e230449. Available from: https://doi.org/10.1098/rsos.230449

Nishijima, S., Nishikawa, C. & Miyashita, T. (2017) Habitat modification by invasive crayfish can facilitate its growth through enhanced food accessibility. *BMC Ecology*, 17, e37. Available from: https://doi.org/10.1186/s12898-017-0147-7

Oliveira-Junior, J.M.B. & Juen, L. (2019) The Zygoptera/Anisoptera ratio (Insecta: Odonata): a new tool for habitat alterations assessment in Amazonian streams. *Neotropical Entomology*, 48, 552–560. Available from: https://doi.org/10.1007/s13744-019-00672-x

Orr, J.A., Macaulay, S.J., Mordente, A., Burgess, B., Albini, D., Hunn, J.G. et al. (2024) Studying interactions among anthropogenic stressors in freshwater ecosystems: a systematic review of 2396 multiple-stressor experiments. *Ecology Letters*, 27, e14463. Available from: https://doi.org/10.1111/ele.14463

Ožana, S., Burda, M., Hykel, M., Malina, M., Prášek, M., Bárta, D. et al. (2019) Dragonfly hunter CZ: Mobile application for biological species recognition in citizen science. *PLoS One*, 14, e0210370. Available from: https://doi.org/10.1371/journal.pone.0210370

Pereira, D.F.G., Oliveira Junior, J.M.B. & Juen, L. (2019) Environmental changes promote larger species of Odonata (Insecta) in Amazonian streams. *Ecological Indicators*, 98, 179–192. Available from: https://doi.org/10.1016/j.ecolind.2018.09.020

Perron, M.A.C., Bried, J.T., Richmond, I.C. & Charette, C. (2024) Urban stormwater ponds can support dragonfly reproduction akin to natural ponds. *International Journal of Odonatology*, 27, 187–199. Available from: https://doi.org/10.49156/1388.2024.1917292

Perron, M.A.C. & Pick, F.R. (2020) Stormwater ponds as habitat for Odonata in urban areas: the importance of obligate wetland plant species. *Biodiversity and Conservation*, 29, 913–931. Available from: https://doi.org/10.1007/s10531-019-01917-2

Pires, M., Martins, F., del Palacio, A., Muzón, J., Vareira, L., Juen, L. et al. (2024) Assessing the spatial knowledge gaps of Odonata diversity and conservation in the south American Pampa. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 34(5), e4161. Available from: https://doi.org/10.1002/aqc.4161

Popova, O.N., Haritonov, A.Y., Sushchik, N.N., Makhutova, O.N., Kalachova, G.S., Kolmakova, A.A. et al. (2017) Export of aquatic productivity, including highly unsaturated fatty acids, to terrestrial ecosystems via Odonata. *Science of the Total Environment*, 581, 40–48. Available from: https://doi.org/10.1016/j.scitotenv.2017.01.017

Pozojević, I., Dorić, V., Miliša, M., Ternjej, I. & Ivković, M. (2023) Defining patterns and rates of natural vs. drought driven aquatic community variability indicates the ongoing need for long term ecological research. *Biology*, 12, e590. Available from: https://doi.org/10.3390/biology12040590

Pryce, D. (2021) Sympetrum dilatatum. The IUCN Red List of Threatened Species 2021, eT21226A193512121. https://doi.org/10.2305/IUCN.UK.2021-3.RLTS.T21226A193512121.en Accessed on 04 July 2024.

Reid, A.J., Carlson, A.K., Creed, I.F., Eliason, E.J., Gell, P.A., Johnson, P.T. et al. (2019) Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews of the Cambridge Philosophical Society*, 94(3), 849–873. Available from: https://doi.org/10.1111/brv.12480

Ribeiro, C., Juen, L. & Rodrigues, M.E. (2021) The Zygoptera/Anisoptera ratio as a tool to assess anthropogenic changes in Atlantic Forest streams. *Biodiversity and Conservation*, 30, 1315–1329. Available from: https://doi.org/10.1007/s10531-021-02143-5

Rivas-Torres, A. & Cordero-Rivera, A. (2024) A review of density, biomass and secondary production of odonates. *Insects*, 15, e510. Available from: https://www.mdpi.com/2075-4450/15/7/510

Rocha-Ortega, M., Khelifa, R., Sandall, E.L., Deacon, C., Sanchez-Rivero, X., Pinkert, S. et al. (2023) Linking traits to extinction risk in Odonata. In: Córdoba-Aguilar, A., Beatty, C.D. & Bried, J.T. (Eds.) *Dragonflies and damselflies: model organisms for ecological and evolutionary research*, 2nd edition. New York, USA: Oxford University Press, pp. 343–358. Available from: https://doi.org/10.1093/oso/9780192898623.003.0024

Rocha-Ortega, M., Rodriguez, P., Bried, J., Abbott, J. & Cordoba-Aguilar, C. (2020) Why do bugs perish? Range size and local vulnerability traits as surrogates of Odonata extinction risk. *Proceedings of the Royal Society B*, 287, e20192645. Available from: https://doi.org/10.1098/rspb.2019.2645

Rocha-Ortega, M., Rodríguez, P. & Córdoba-Aguilar, A. (2019) Spatial and temporal effects of land use change as potential drivers of odonate community composition but not species richness. *Biodiversity and Conservation*, 28, 451–466. Available from: https://doi.org/10.1007/s10531-018-1671-2

Rykiel, E.J. (1985) Towards a definition of ecological disturbance. *Australian Journal of Ecology*, 10, 361–365. Available from: https://doi.org/10.1111/j.1442-9993.1985.tb00897.x

Samways, M.J. (1989) Farm dams as nature reserves for dragonflies (Odonata) at various altitudes in the Natal Drakensberg mountains, South Africa. *Biological Conservation*, 48, 181–187. Available from: https://doi.org/10.1016/0006-3207(89)90117-1

Samways, M.J. (2024) *Conservation of dragonflies: sentinels for freshwater conservation*. Wallingford, UK: CABI/Royal Entomological Society. Available from: https://doi.org/10.1079/9781789248395.0007

Samways, M.J. & Sharratt, N.J. (2010) Recovery of endemic dragonflies after removal of invasive alien trees. *Conservation Biology*, 24, 267–277. Available from: https://doi.org/10.1111/j.1523-1739.2009.01427.x

Samways, M.J. & Simaika, J.P. (2016) *Manual of freshwater assessment: dragonfly biotic index*. Pretoria, South Africa: South African National Biodiversity Institute. 978-1-928224-05-1.

Samways, M.J. & Taylor, S. (2004) Impacts of invasive alien plants on red-listed south African dragonflies (Odonata): working for water. *South African Journal of Science*, 100, 78–80.

Sanchez Herrera, M., Forero, D., Calor, A.R., Romero, G.Q., Riyaz, M., Callisto, M. et al. (2024) Systematic challenges and opportunities in insect monitoring: a global south perspective. *Philosophical Transactions of the Royal Society B*, 379, e20230102. Available from: https://doi.org/10.1098/rstb.2023.0102

Sayer, C.A., Fernando, E., Jimenez, R.R., Macfarlane, N.B., Rapacciuolo, G., Böhm, M. et al. (2025) One-quarter of freshwater fauna threatened with extinction. *Nature*, 638(8049), 1–8. Available from: https://doi.org/10.1038/s41586-024-08375-z

Schmidt, K.J., Soluk, D.A., Mays Maestas, S.E. & Britten, H.B. (2021) Persistence and accumulation of environmental DNA from an endangered dragonfly. *Scientific Reports*, 11, 18987. Available from: https://doi.org/10.1038/s41598-021-98099-1

Sheard, J.K., Adriaens, T., Bowler, D.E., Büermann, A., Callaghan, C.T., Camprasse, E.C.M. et al. (2024) Emerging technologies in citizen science and potential for insect monitoring. *Philosophical Transactions of the Royal Society B*, 379, 20230106. Available from: https://doi.org/10.1098/rstb.2023.0106

Šigutová, H., Bílková, E., Ožana, S. & Dolný, A. (2025) Small whiteface (Leucorrhinia dubia: Odonata) reintroduction update highlights the importance of long-term monitoring and regular habitat management. *Insect Conservation and Diversity*, 2025, 1–10. Available from: https://doi.org/10.1111/icad.12809

Šigutová, H., Dolný, A., Samways, M.J., Hardersen, S., Oliveira-Junior, J.M., Juen, L. et al. (2023) Odonata as indicators of pollution, habitat quality, and landscape disturbance. In: Córdoba-Aguilar, A., Beatty, C.D. & Bried, J.T. (Eds.) *Dragonflies and damselflies: model organisms for ecological and evolutionary research*, 2nd edition. New York, USA: Oxford University Press, pp. 371–384. Available from: https://doi.org/10.1093/oso/9780192898623.003.0026

Šigutová, H., Pyszko, P., Bílková, E., Prieložná, V. & Dolný, A. (2024) Sum or mean in calculation of qualitative scoring methods using the dragonfly biotic index, and an alternative approach facilitating conservation prioritization. *Scientific Reports*, 14, e11356. Available from: https://doi.org/10.1038/s41598-024-62017-y

Šigutová, H., Pyszko, P., Valušák, J. & Dolný, A. (2022) Highway stormwater ponds as islands of Odonata diversity in an agricultural landscape. *Science of the Total Environment*, 837, e155774. Available from: https://doi.org/10.1016/j.scitotenv.2022.155774

Šigutová, H., Šigut, M. & Dolný, A. (2015) Intensive fish ponds as ecological traps for dragonflies: an imminent threat to the endangered species Sympetrum depressiusculum (Odonata: Libellulidae). *Journal of Insect Conservation*, 19, 961–974. Available from: https://doi.org/10.1007/s10841-015-9813-2

Simonsen, T.J., Olsen, K. & Djernæs, M. (2020) The African-Iberian connection in Odonata: mtDNA and ncDNA based phylogeography of Aeshna cyanea (Müller, 1764) (Odonata: Aeshnidae) in Western Palaearctic. *Arthropod Systematics and Phylogeny*, 78, 309–320. Available from: https://doi.org/10.26049/ASP78-2-2020-06

Smith, B.D., Villalobos-Jiménez, G., Perron, M.A.C., Sahlén, G., Assandri, G., Vilenica, M. et al. (2023) Odonata assemblages in human-modified landscapes. In: Córdoba-Aguilar, A., Beatty, C.D. & Bried, J.T. (Eds.) *Dragonflies and damselflies: model organisms for ecological and evolutionary research*, 2nd edition. New York, USA: Oxford University Press, pp. 247–260.

Steytler, N.S. & Samways, M.J. (1995) Biotope selection by adult male dragonflies (Odonata) at an artificial lake created for insect conservation in South Africa. *Biological Conservation*, 72, 381–386. Available from: https://doi.org/10.1016/0006-3207(94)00052-R

Streib, L., Juvigny-Khenafou, N., Heer, H., Kattwinkel, M. & Schäfer, R.B. (2022) Spatiotemporal dynamics drive synergism of land use and climatic extreme events in insect meta-populations. *Science of the Total Environment*, 814, e152602. Available from: https://doi.org/10.1016/j.scitotenv.2021.152602

Suárez-Tovar, C.M., Castillo-Pérez, E.U., Sandoval-García, I.A., Schondube, J.E., Cano-Santana, Z. & Córdoba-Aguilar, A. (2022) Resilient dragons: exploring Odonata communities in an urbanization gradient. *Ecological Indicators*, 141, e109134. Available from: https://doi.org/10.1016/j.ecolind.2022.109134

Suárez-Tovar, C.M., da Silva Pereira, J.L., Rocha, T., Rivera-Duarte, J.D., Juen, L. & Córdoba-Aguilar, A. (2024) Fierce city hunters: more effective predation of dragonflies and damselflies in urbanized areas. *Animal Behaviour*, 208, 51–58. Available from: https://doi.org/10.1016/j.anbehav.2023.12.002

Sugita, N., Agemori, H. & Goka, K. (2018) Acute toxicity of neonicotinoids and some insecticides to first instar nymphs of a non-target damselfly, Ischnura senegalensis (Odonata: Coenagrionidae), in Japanese paddy fields. *Applied Entomology and Zoology*, 53, 519–524. Available from: https://doi.org/10.1007/s13355-018-0583-7

Suhling, F., Sahlén, G., Martens, A., Marais, E. & Schütte, C. (2006) Dragonfly assemblages in arid tropical environments: a case study from western Namibia. *Biodiversity and Conservation*, 15, 311–332. Available from: https://doi.org/10.1007/s10531-005-2007-6

Taylor, P.D. (2006) Movement behaviors of a forest odonate in two heterogenous landscapes. In: Cordero-Rivera, A. (Ed.) *Forests and dragonflies*. Sophia, Bulgaria: Pensoft, pp. 225–238.

Termaat, T., Ketelaar, R., van Kleef, H.H., Verberk, W.C.E.P., van Grunsven, R.H.A. & De Wallis Vries, M.F. (2023) Spearhead blues: how threats to the damselfly Coenagrion hastulatum changed over time. *Journal of Insect Conservation*, 28, 211–224. Available from: https://doi.org/10.1007/s10841-023-00537-0

Termaat, T., van Strien, A.J., van Grunsven, R.H.A., De Knijf, G., Bjelke, U., Burbach, K. et al. (2019) Distribution trends of European dragonflies under climate change. *Diversity and Distributions*, 25, 936–950. Available from: https://doi.org/10.1111/ddi.12913

Tramblay, Y., Koutroulis, A., Samaniego, L., Vicente-Serrano, S.M., Volaire, F., Boone, A. et al. (2020) Challenges for drought assessment in the Mediterranean region under future climate scenarios. *Earth-Science Reviews*, 210, e103348. Available from: https://doi.org/10.1016/j.earscirev.2020.103348

Trisos, C.H., Auerbach, J. & Katti, M. (2021) Decoloniality and anti-oppressive practices for a more ethical ecology. *Nature Ecology & Evolution*, 5, 1205–1212. Available from: https://doi.org/10.1038/s41559-021-01460-w

Tüzün, N. & Stoks, R. (2017) Carry-over effects across metamorphosis of a pesticide on female lifetime fitness strongly depend on egg hatching phenology: a longitudinal study under seminatural conditions. *Environmental Science and Technology*, 51, 13949–13956. Available from: https://doi.org/10.1021/acs.est.7b04399

Tynkkynen, K., Kotiaho, J.S. & Svensson, E. (2008) Interspecific interactions and premating reproductive isolation. In: Córdoba-Aguilar, A. (Ed.) *Dragonflies and damselflies: model organisms for ecological and evolutionary research*. New York. USA: Oxford University Press, pp. 139–152.

van Schalkwyk, J., Kietzka, G.J., Pryke, J.S., Gaigher, R. & Samways, M.J. (2023) Enhancing semi-aquatic species representativeness beyond protected areas: dragonflies in networks of conservation corridors. *Biodiversity and Conservation*, 32, 3991–4005. Available from: https://doi.org/10.1007/s10531-023-02678-9

van Strien, A.J. & Grunsven, R.H.A. (2023) In the past 100 years dragonflies declined and recovered by habitat restoration and climate change. *Biological Conservation*, 277, e109865. Available from: https://doi.org/10.1016/j.biocon.2022.109865

Veseli, M., Rožman, M., Vilenica, M., Petrović, M. & Previšić, A. (2022) Bioaccumulation and bioamplification of pharmaceuticals and endocrine disruptors in aquatic insects. *Science of the Total Environment*, 838, 156208. Available from: https://doi.org/10.1016/J.SCITOTENV.2022.156208

Vilenica, M., Brigić, A., Ergović, V., Koh, M., Alegro, A., Šegota, V. et al. (2024) Taxonomic and functional Odonata assemblage metrics: macrophyte–driven changes in anthropogenically disturbed floodplain habitats. *Hydrobiologia*, 851, 3787–3807. Available from: https://doi.org/10.1007/s10750-024-05541-2

Vilenica, M., Brigić, A., Štih Koren, A., Koren, T., Sertić Perić, M., Schmidt, B. et al. (2024) Odonata assemblages in urban semi-natural wetlands. *Insects*, 15(3), e207. Available from: https://doi.org/10.3390/insects15030207

Vilenica, M. & Mihaljević, Z. (2022) Odonata assemblages in anthropogenically impacted habitats in the Drava River—a long-term study. *Water*, 14, e3119. Available from: https://doi.org/10.3390/w14193119

Vilenica, M., Pozojević, I., Vučković, N. & Mihaljević, Z. (2020) How suitable are man-made water bodies as habitats for Odonata? *Knowledge and Management of Aquatic Ecosystems*, 421, e13. Available from: https://doi.org/10.1051/kmae/2020008

Vorster, C., Samways, M.J., Simaika, J.P., Kipping, J., Clausnitzer, V., Suhling, F. et al. (2020) Development of a new continental-scale index for freshwater assessment based on dragonfly assemblages. *Ecological Indicators*, 109, e105819. Available from: https://doi.org/10.1016/j.ecolind.2019.105819

Vukoja, A., Bogdanović, T., Rašeta, D., Miljanić, N., Risek, I.I., Ilić, K. et al. (2024) Dragonflies (Odonata) as bioindicators of radioactivity. *Isotopes in Environmental and Health Studies*, 2024, 1–9. Available from: https://doi.org/10.1080/10256016.2024.2425070

Waller, J.T., Willink, B., Tschol, M. & Svensson, E.I. (2019) The odonate phenotypic database, a new open data resource for comparative studies of an old insect order. *Scientific Data*, 6, 316. Available from: https://doi.org/10.1038/s41597-019-0318-9

Wildermuth, H. & Schiess, H. (1983) Die Bedeutung praktischer Naturschutzmaßnahmen für die Erhaltung der Libellenfauna in Mitteleuropa. *Odonatologica*, 12, 345–366.

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